American Shad restoration in three Maryland rivers

F-57-R Segment 15 Progress Report
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Need

American Shad *Alosa sapidissima* was once the most important commercial and recreational fish species in the Chesapeake Bay. In response to severe population declines from 1900 to the 1970s, Maryland closed its fishery in 1980. Various factors that contributed to the decline include over-fishing, stream blockages and poor water quality (Hildebrand and Schroeder 1928). Severely depressed or extirpated native adult stocks do not presently utilize most Chesapeake Bay tributaries, including the Choptank River (Klauda et al. 1991). This tributary historically supported commercially fished spawning stocks (Mansueti and Kolb 1953). Improvements in water quality, sustained fishing moratorium and removal of many stream blockages has reopened potential shad spawning habitat in the Chesapeake Bay. Since shad populations indicate evidence of density dependent spawning behavior, self-sustaining shad populations are not likely to return to tributaries without hatchery stocking. Development of spawning, culture, marking and stocking techniques could restore spawning populations of American Shad to this target tributary.

Objective

The overall objective for this proposed scope of work is to restore self-sustaining American Shad populations to the Choptank River. Prior to project inception, the depressed native stocks in the Choptank River did not exhibit any evidence of spawning activity, according to exploratory sampling efforts in the early 1990s. This tributary supported spawning runs and active commercial and recreational fisheries in the past.

Expected Results and Benefits

Hatchery contributions are intended to provide adult spawners that will produce self-sustaining populations in the target tributary. These fish have tremendous value for stock assessment purposes at the larval, juvenile and adult life stages since all stocked shad receive an otolith mark and/or numeric coded wire tag (CWT, Northwest Marine Technologies, Shaw Island, Washington, USA).CWT marking was discontinued in 2010 in favor of a less labor intensive feed marking technique. Natural spawn and strip spawn culture techniques allow for the production of large numbers of larval and juvenile shad for stocking and assessment efforts.

Upper Bay and Potomac River shad populations currently support active catch and release recreational fishing. Restoring shad stocks to tributaries that historically supported runs will increase fishing opportunities for anglers. Recreational fishing that targets American Shad is

beginning to occur in the Patuxent River and Choptank River. An indirect benefit of restoring shad populations to self-sustainable levels is the increased prey availability provided by both adult and juvenile shad for larger, more economically important recreational species such as striped bass, bluefish, and weakfish.

Approach

Maryland Department of Natural Resources (MDNR) began a pilot project in 1993 to assess the response of American Shad adult broodstock during collection, handling and captive holding. In 1994, experimental spawning was conducted using timed-release hormone implants. The success of these trials encouraged development of a long-term spawning, culture, stocking and assessment program. In 1995, a non-funded, full-scale hatchery production effort was conducted with positive results. The project continued over the next three years through various short-term funding sources. In 1998, it was determined that a long term funding source would be required since it would take years of additional stocking and assessment to successfully support restoration. Federal Aid in Sport Fish Restoration funds have been utilized to conduct this long-term effort.

The project consists of three sub-projects:

1. *Produce, mark and stock cultured American Shad in the Choptank River.*
2. *A. "Assess the contribution of hatchery-produced fish on the resident/pre-migratory stock in the Patuxent River and Choptank River."*
   B. "Monitor the abundance and mortality of larval and juvenile shad using marked hatchery-produced fish".
3. Analyze the contribution of hatchery origin American Shad to the adult spawning population and monitor the recovery of naturally produced stocks.

Justification to amend approach

Federally funded Choptank River and Patuxent River restoration work began in 1999. Marshyhope Creek, a Nanticoke River tributary, was added in 2001. MDNR previously documented some encouraging progress with restoration of these species in Maryland. Beginning in 2006 however, most Atlantic Coast states began to observe decreased numbers in migratory Alosine stocks. It is hypothesized that mortality is occurring to out-migrating young-of-year shad or sub-adults in coastal waters.

A proposal was submitted to U.S. Fish & Wildlife Service Wildlife Sport Fish

Restoration in December 2009 to continue funding for F-57-R, Restoration of American Shad and hickory shad in three Maryland Rivers. The scope of work described a five-year continuation of previous shad restoration work in Maryland that was conducted in the Patuxent River, Choptank River and Marshyhope Creek. After careful consideration of recent shad population trends, both in Maryland and along the entire Atlantic coast, project biologists determined that a change in approach was warranted for this restoration project.

Project biologists discussed the most responsible course of action considering recent developments and analysis of the 2009 data. In 2010 the grant proposal was amended to suspend stocking the Patuxent River and Marshyhope Creek and to apply all project resources towards stocking and monitoring in the Choptank River. Limited monitoring of adults and juveniles will continue in the Patuxent River in order to maintain trend data.

Location

Restoration efforts will occur in the Choptank River (Figure 1). The Choptank River watershed is rural-impacted by agricultural activities and low urban development. Choptank River efforts include the tributary of Tuckahoe Creek.

Sub-project 1.

"Produce, mark and stock cultured American Shad in the Choptank River."

In 2014, MDNR staff produced, marked, and stocked American Shad larvae and juveniles. American Shad production needs were met by strip spawning brood fish from the Potomac River (Figure 2). American Shad larvae, early juveniles and late juveniles were cultured, marked, and stocked in the Choptank River (Figure 1). Larval fish were stocked into rivers immediately after being marked with a day 3, 6 and 10 oxytetracycline (OTC) mark. Early juvenile fish were marked with OTC on day 3 and 6 stocked as larvae into hatchery ponds and transported to the rivers at approximately 30 days of age. Late juvenile fish were stocked as larvae with an OTC day 3,6 mark into hatchery ponds, then at approximately 30 days of age were removed from the hatchery ponds, moved to indoor tanks, intensively cultured to approximately 75.0 mm total length (TL) and marked with one 10 day OTC feed mark. In 2014, late juveniles were stocked only in the Choptank River at the Denton boat ramp.

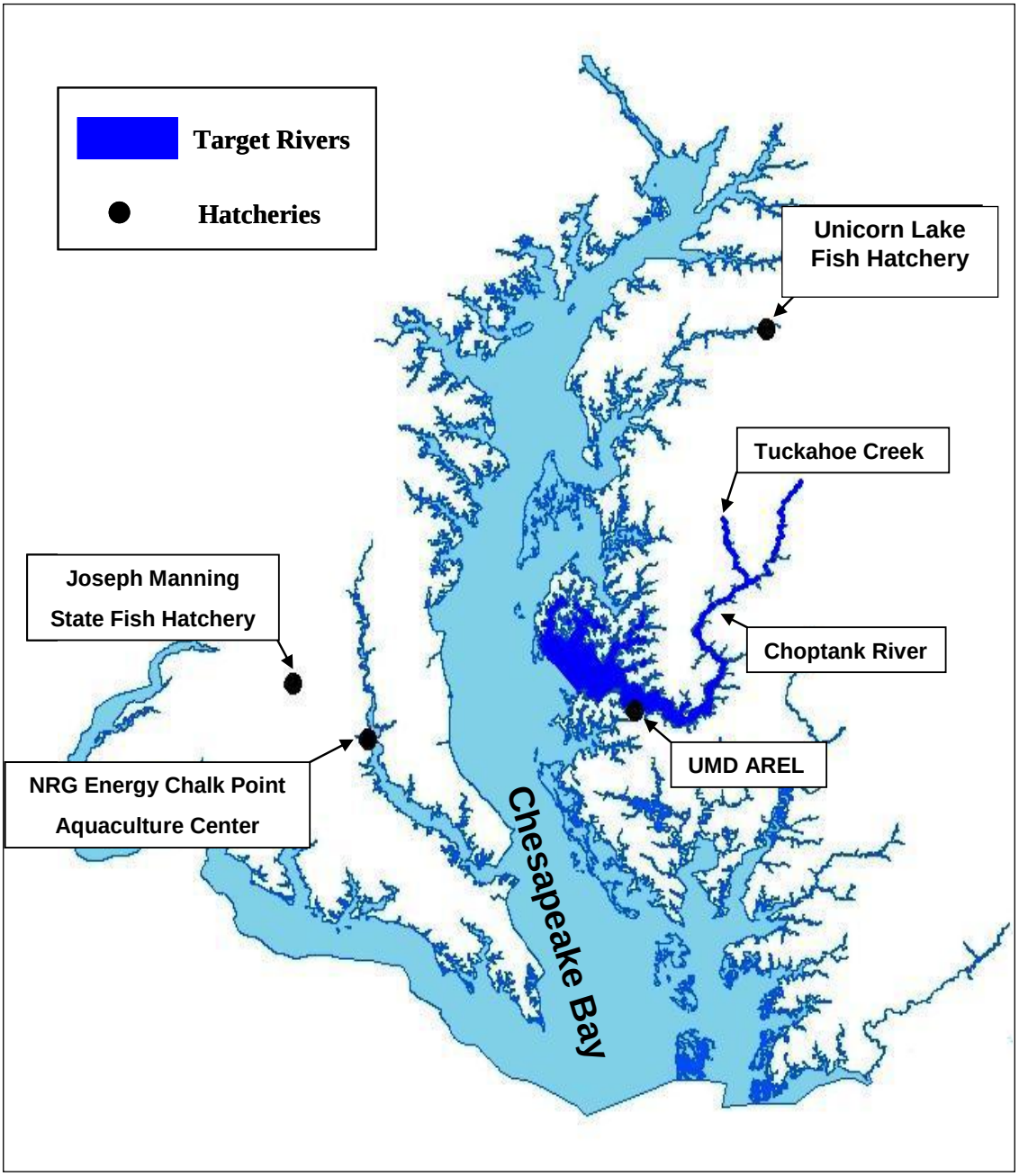

Figure 1. *2014 target tributary and culture sites for Maryland Department of Natural Resources shad restoration project. NRG Energy Chalk Point is a power company that cultures fish for the restoration effort. The Horn Point Aquaculture Restoration and Ecology Laboratory (AREL), is a University of Maryland (UMD) facility that supplies culture ponds for the restoration effort.*

Materials and Methods

Brood Stock Collection

American Shad were originally produced utilizing tank spawn culture methods developed by the project. Declining production success of American Shad from tank spawn operations dictated that an additional source of larvae be developed.

In 2001, the decision was made to collect ripe fish on the spawning grounds and manually strip eggs and milt from mature brood fish. The Potomac River was chosen as the source population due to its healthy American Shad spawning population. The project hired a commercial fisherman to assist in egg collections that year. In 2002, it was determined that project personnel could perform these collections more efficiently and economically than the commercial fisherman and this method is still utilized today. Different areas along the Potomac River were evaluated for their ability to concentrate American Shad. It was determined that the channel in front of Fort Belvoir concentrates the greatest amount of American Shad (Figure 2). The collections were carried out aboard a 7.0 m flat-bottom, center console skiff equipped with an outboard motor.

Weather and temperature conditions in late March and early April greatly influence the timing of American Shad spawning on the Potomac River. It is essential to begin sampling in early April to ensure that collections occur during peak shad spawn. Sampling begins when water temperatures are 14 to 16°C. In early April, the majority of captured American Shad females are gravid, but not yet ripe for egg collection. In early May, most captured females are ripe and appropriate for egg collection. Spent females also begin to appear at this time. Gradually, the composition shifts so that most captured females are spent. Broodstock collections conclude after this shift to a majority of spent females. Contribution to hatchery production is low at this point.

Gill nets were set parallel to the channel edge at depths varying between approximately 7.0 and 18.0 m. The time of net set depended exclusively on tide. Nets were ideally set at the beginning of slack tide. Past efforts indicated that setting nets at or near slack tide had a tendency to collect more shad. Nets were allowed to fish for approximately one hour. American Shad are predisposed to spawn near, or just after sundown (Mansueti and Kolb 1953). Nets were set during the period from 1530 to 2130. Collecting shad before or after this six-hour window was deemed ineffective.

Catch per unit effort (CPUE) is used as an index of relative abundance. Gill net CPUE is established by dividing the number of fish caught per net, by the square footage of net fished per

hour of soak time. A hand tally counter (tallycounterstore.com) is used to keep accurate count of all American Shad caught from each net. Although trends in overall American Shad catch rates can be monitored using CPUE (Figure 3), the use of non-standardized gear through the years makes it difficult to establish an accurate relative abundance over time. CPUE is an accurate tool to evaluate the most efficient gear to collect American Shad. Net CPUE differs greatly based on the net construction (monofilament vs. multifilament), net mesh size, and net depth.

Two different nets were evaluated to study catch efficiency using different net mesh size and net depth. Gill nets with smaller mesh size have the tendency to catch smaller fish while nets with larger mesh sizes have a tendency to catch larger fish. In 2014, MDNR staff fished typically two size types of floating gill nets a majority (97%) of the time. A smaller stretch mesh net (117.5mm) was fished on 14 and 16 May to try to collect an increased number of males. This net collected only 4.1% of the total males collected during the season. The two net sizes fished throughout the collection season exhibited similar catch efficiency (Figure 4).

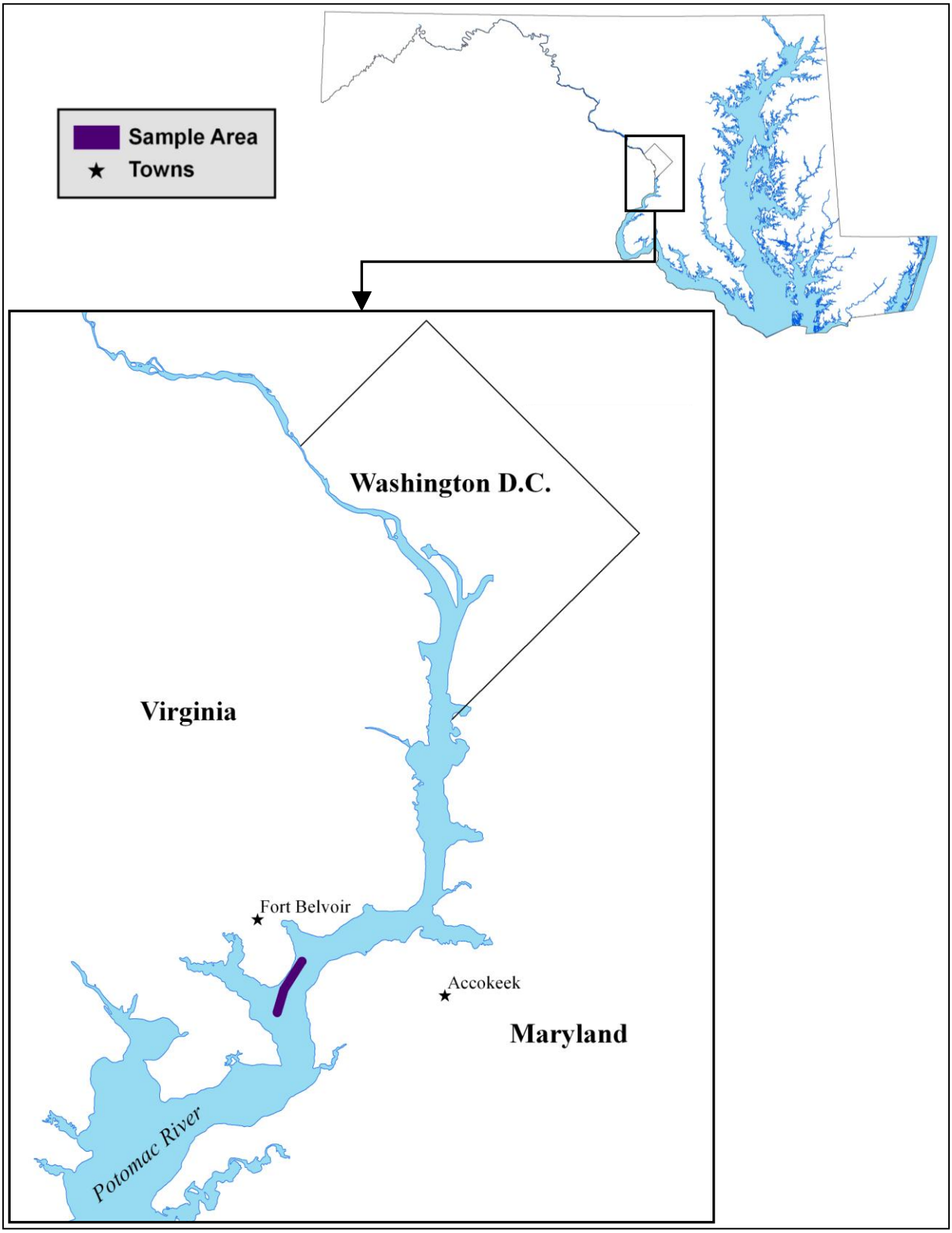

Figure 2. *2014 Maryland Department of Natural Resources American Shad brood stock collection site on the Potomac River.*

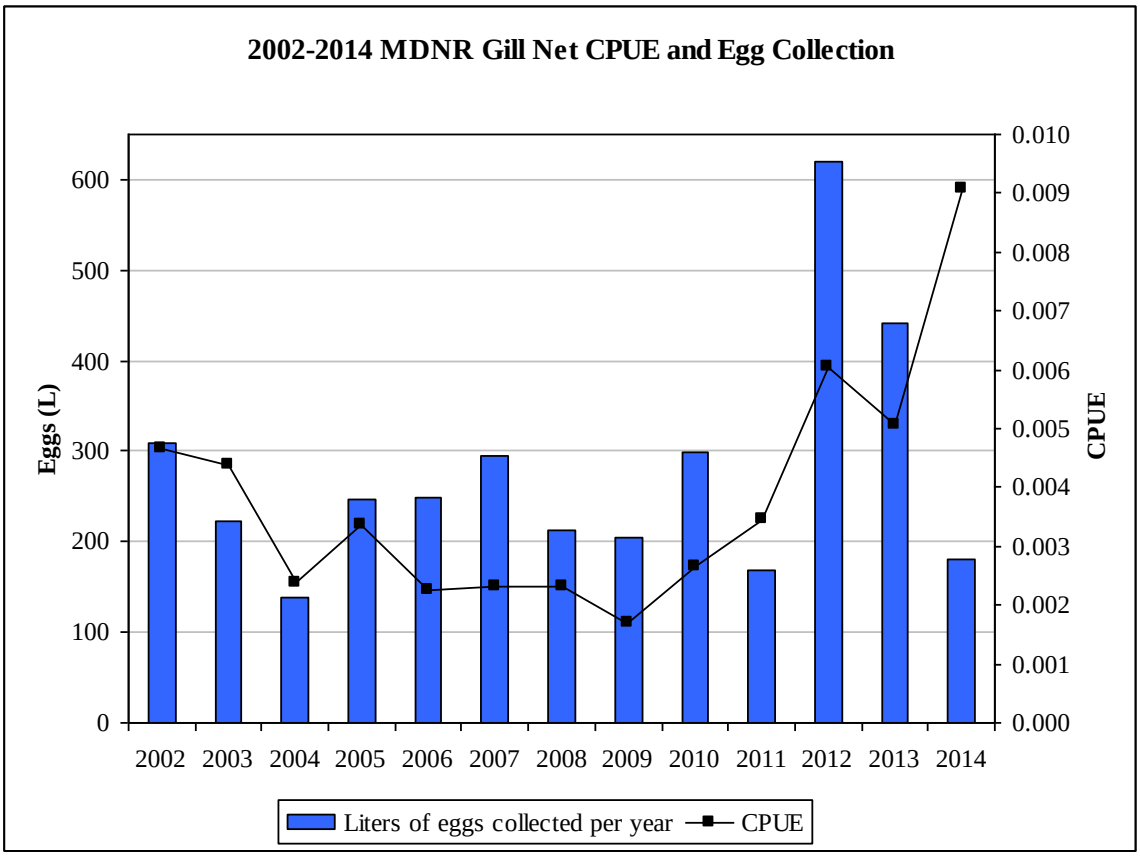

Figure 3. *2002-2014 Maryland Department of Natural Resources gill net CPUE and egg collection on the Potomac River.*

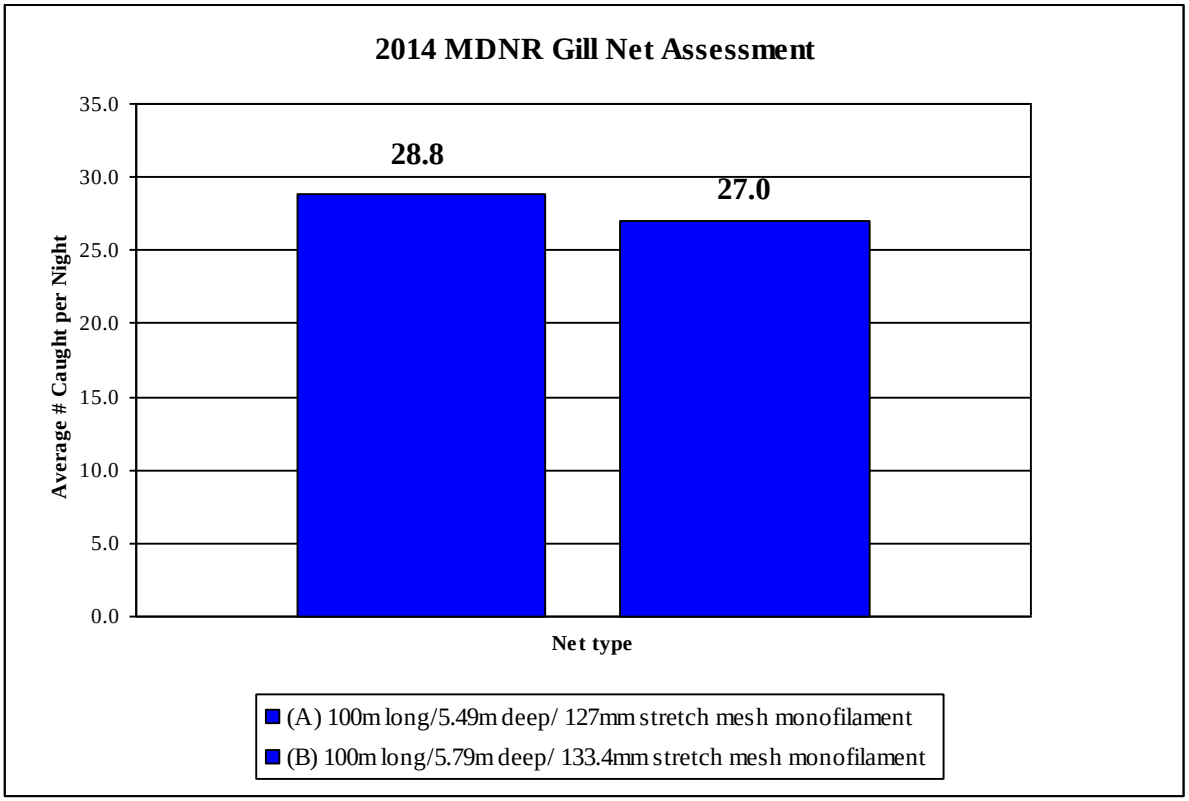

Figure 4. *2014 Maryland Department of Natural Resources American Shad gill net assessment on the Potomac River.*

Egg Fertilization and Culture

Egg fertilization was conducted aboard a flat deck fiberglass skiff on the Potomac River. Ripe females and males were removed from gill nets and placed into separate water-filled holding tubs on the boat. Eggs were manually stripped into clean, dry bowls and milt was deposited over the eggs using the dry method described by Howey (1985). River water was then added to activate the sperm and allowed to set for 10 minutes. Fertilized eggs were rinsed to be cleaned of any blood or ovarian tissue that might be present and carefully poured into a floating egg box for at least one hour to water harden. This minimized egg damage during transport to the hatchery. Pure oxygen was used in the egg boxes during transport. The floating egg boxes were placed on the deck of the boat and transported to Manning State Fish Hatchery (Brandywine, Maryland) for culture (Figure 1).

Eggs were placed in modified McDonald hatching jars supplied by approximately 2.0 L/min water flow. Prophylactic treatments of formalin were administered in the morning and afternoon to control fungi. Eggs were exposed to a 600:1 treatment of formalin for approximately 17 min. Eggs were volumetrically measured at the hatchery and percent fertilization was determined 24 hours post-fertilization.

American Shad eggs began hatching at day six. In order to stimulate a simultaneous hatch, jars were removed from the egg bank, placed outdoors in sunlight for ten minutes and stirred occasionally. The increased temperature, lower oxygen content, concentrated hormonal influence and agitation stimulated simultaneous hatching. Jars were then placed around 1.5 m circular, flow-through larval tanks. Water was supplied at approximately 2.0 L/min. Larvae flowed into circular culture tanks after hatch.

Food was introduced to American Shad at day three. American Shad larvae were fed live *Artemia sp*. (www.brineshrimpdirect.com) and 100µm AP100 larval fish food (Zeigler Bros, Gardners, PA) three times daily during daylight hours.

Prior to stocking, larvae were enumerated using a volumetric direct proportion procedure in which a columnar sample of water was collected with a 25.0 mm diameter PVC tube at random locations in the larval tank. Larvae were enumerated in this sample and the total number of larvae in the tank was estimated by extrapolation to the total tank volume. In addition to this enumeration method, eggs are volumetrically measured and counted while performing the fertilization procedure.

Marking

All fish stocked into target tributaries were given an OTC mark through larval immersion. OTC marking is a valuable assessment tool to determine hatchery origin, larval survival and juvenile abundance and mortality estimates. Larval marks were produced by immersion in a 300 ppm buffered OTC bath for six hours. Dissolved oxygen (D.O.) content was monitored and regulated (>5.0 ppm) by a carbon air stone connected to a liquid oxygen delivery system. All water used at Manning Hatchery for OTC marking was softened before use (Culligan ion exchange system). Reliable marking can only take place in water with hardness below 20 mg/L and water hardness at Manning Hatchery routinely exceeds 200 mg/L. Samples analyzed from each group of OTC-marked fish indicated that all fish stocked were successfully marked. Marks were verified by viewing larval otoliths with an ultraviolet microscope (Zeiss Axioskop). Beginning in 2009, a three-year rotating, year-specific mark for larval stocked American Shad was implemented. This procedure will validate current shad ageing protocols for adult, hatchery-origin American Shad collected. The rotating marks for larval stocked American Shad will be: 2009 (day 3), 2010 (day 3, 9), 2011 (day 3, 6, 10), 2012 (day 3), 2013 (day 3, 9) and 2014 (day 3, 6, 10). This research protocol was recommended by the Atlantic States Marine Fisheries Commission American Shad and River Herring Technical Committee (ASMFC). Larvae designated for early juvenile stocking were given a day 3, 6 mark. Larvae designated for late juvenile stocking were given a day 3, 6 mark and a 10- day feed mark under the protocol of (Investigational New Animal Drug (INAD) 9332).

Larval Stocking

In 2014 fish intended for larval stocking received a larval immersion mark at day 3, 6, and 10 after hatch. Stocking was accomplished by placing OTC-marked larvae into boxes originally designed for shipping tropical fish. These containers consisted of an outer shell cardboard box, an inner insulating foam box, a black plastic trash bag to reduce stress of bright sunlight and a double thickness plastic fish bag. Larval culture tanks were drawn down to crowd the fish. Larvae were scooped out of the tanks using modified milk jugs and placed in the shipping bags/boxes, which were supplemented with approximately 1.0 ppt salt to mitigate stress. Each bag was filled with pure oxygen and sealed with electricians tape. Boxes were driven to the Choptank River at Greensboro (Figure 6). The bags were placed in the water long

enough to temperature acclimate. The bags were then opened and river water was slowly introduced to further acclimate larvae to river water conditions. Bags were then emptied into flowing water to minimize predation.

Early Juvenile Stocking

Fish intended for early juvenile stocking received immersion marks at day three and six after hatch. After the second mark was administered, larvae were stocked into hatchery ponds for approximately thirty days. Manning Hatchery, NRG Energy, Unicorn Lake Hatchery and the University of Maryland (UMD) Aquaculture and Restoration Ecology Laboratory (AREL) Horn Point provide grow out ponds to hold fish for the restoration effort (Figure 1). The decision to take juveniles out of the pond was based on zooplankton density. Food availability in grow out ponds was evaluated with a plankton net. Early juveniles were removed from culture ponds when food availability declined.

Juvenile fish tend to stress easily and direct netting from hatchery ponds into transport tanks is not recommended. Juvenile fish were concentrated with a seine net 61.0 meters long, 3.1 meters deep, with 6.4mm stretch mesh and bucketed with pond water into the transport tank. A small one horse power water pump was used to create current within the seine net to orient shad into the water flow. This current serves two purposes. Shad are concentrated in the flow for bucketing ease, and it separates the fish from the algae and detritus. Early juvenile survival increased in recent years due to the reduction of algae and detritus in the transport tanks. Early juveniles were transported to the Choptank River at the Denton boat ramp and the Tuckahoe Creek at Stony Point in fish hauling tanks at 3.0-5.0 ppt. salinity and D.O. saturation to mitigate stress. Ponds at NRG Energy and AREL already have elevated salinity of 6.0-8.0 ppt. Juvenile stocking was accomplished by quick-dumping tagged juveniles through a 15.0 cm hose directly from the transport vehicle into the river.

A one-horsepower trash pump was carried on the stocking truck to temper juvenile shad before stocking. Fish were tempered until temperature and salinity in the tank were within one degree Celsius and 1.0 ppt salinity of the river value. Although this adds a considerable amount of time that fish are aboard the transport tank, it is assumed this procedure increases the survival of early juvenile stocked shad by reducing stress.

Late Juvenile Stocking

Fish intended for late juvenile stocking were first placed in hatchery ponds and cultured according to methods described for early juvenile stocking. After approximately 30 days, fish

were transferred to indoor intensive culture grow-out tanks. Juveniles were trained to feed (Finfish Starter #1 & #2 diet, Zeigler Bros, Gardners, PA), beginning with hand feeding, then transitioned to belt feeders placed on each culture tank (Aquatic Eco-Systems, Inc., Apopka, FL). In 2014, juveniles received one 10-day OTC otolith feed mark (BioOregon BioVita 1.2mm Terramycin 200). The 10-day OTC feed treatment was administered approximately 80 days after larval hatch.

Prior to 2011, juveniles were reared to approximately 75.0 mm TL for numeric CWT implantation. A one millimeter long CWT was implanted into each fish by dorsal insertion into the muscle at the first pigment spot behind the operculum. Fish handling mortality and tag retention issues with CWT led biologists to explore alternative ways to discretely mark late juvenile shad. In 2010, late juvenile fish were marked with both a 10-day feed mark and implanted with CWT. After verifying the ability to identify the 10-day feed mark, the decision was made to phase out CWT tagging.

Stocking Goals

The project developed stocking goals based on past experience with juvenile collections (Table 1). Stocking multiple life stages gives fisheries managers the ability to assess larval survival and estimate juvenile mortality and abundance of each life stage.

Larval stocked fish can efficiently contribute large numbers of juveniles if survival is high. Fish stocked as early juveniles survive extremely well and are young enough to successfully imprint to the stocked tributary. Stocking early juveniles can also mitigate the impacts of poor larval survival since post-stocking survival of this life stage is high. Late juvenile American Shad are stocked as a valuable assessment tool to estimate juvenile abundance and larval or early juvenile survival. Late juvenile American Shad are believed to imprint poorly to target tributaries since they do not return as adults in similar proportion to their juvenile population contribution.

Table 1. *Maryland Department of Natural Resources 2014 American Shad stocking goals for the Choptank River.*

Stocking phase	Stocking goal
Larvae	2,750,000
Early juvenile	450,000
Late juvenile	50,000

Results and Discussion

American Shad Strip Spawn Production Summary

In 2014, large numbers of ripe female American Shad were collected from the Potomac River spawning area when temperatures ranged from 17°C to 22°C. A consistent increase in water temperature was observed through the 2014 American Shad spawning season until the last week of sampling when temperatures decreased (Figure 5).

Since the inception of the project's gill netting in 2001, a normal bell curve shaped distribution of egg production is observed most years. In 2014 a normal distribution was observed. An elevated level of production was seen for only one week during the collection season (Figure 5).

The decrease in egg production in 2014 was attributed to unfavorable weather conditions through the American Shad spawning season (figure 3). Fish were collected only thirteen sampling nights, below the average number fished in previous years. Heavy rainfall events produced floating debris, turbid water, and extreme tides, which prevented gill net fishing on many nights. Observed CPUE increased in the 2014 season (Figure 3). This could reflect a strong spawning run, but the large number of zero effort sampling events during peak season creates some uncertainty in the 2014 relative abundance data

MDNR collected 3,221 adult American Shad by gill net on the Potomac River. Five hundred and seventy nine ripe females produced 180L of eggs. Overall fertilization was 52.2%. The estimated number of fertilized eggs produced was 3,346,406 (Table 2).

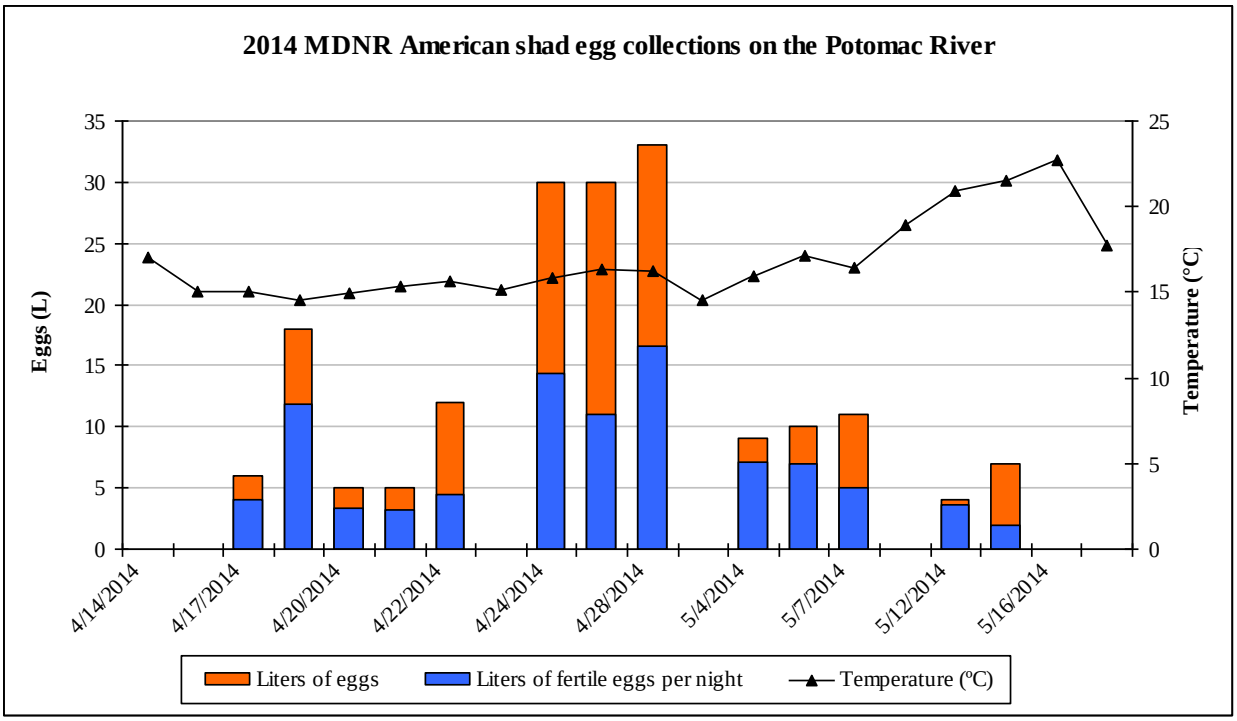

Figure 5. *2014 Maryland Department of Natural Resources volume of total American Shad eggs and viable eggs collected from the Potomac River.*

Table 2. *Maryland Department of Natural Resources American Shad brood fish and production data for 2014. Strip spawn collections were conducted on the Potomac River near Fort Belvoir, Virginia.*

Date	Ripe Females	Total shad	Liters of eggs	Liters of fertile eggs	Egg fertility	Total viable eggs
4/14/2014	7	101	0	0	0.00%	0
4/16/2014	8	111	0	0	0.00%	0
4/17/2014	15	143	6	4	68.00%	130560
4/18/2014	41	163	18	12	65.63%	413,469
4/20/2014	27	147	5	3	68.00%	115,600
4/21/2014	9	163	5	3	65.00%	104,000
4/22/2014	26	215	12	4	37.00%	159,840
4/23/2014	4	96	0	0	0.00%	0
4/24/2014	68	287	30	14	48.00%	504,000
4/27/2014	143	487	30	11	36.86%	437,897
4/28/2014	101	379	33	17	50.40%	598,752
5/01/2014	0	4	0	0	0.00%	0
5/04/2014	23	80	9	7	78.26%	239,476
5/06/2014	26	222	10	7	69.76%	209,280
5/07/2014	28	155	11	5	45.57%	200,508
5/08/2014	5	99	0	0	0.00%	0
5/12/2014	13	109	4	4	90.16%	129,830

5/14/2014	30	217	7	2	28.35%	103,194
5/16/2014	5	41	0	0	0.00%	0
5/18/2014	0	2	0	0	0.00%	0
Total	**579**	**3,221**	**180**	**94**	**52.2%**	**3,346,406**

Stocking Summary

American Shad were stocked as larvae, early juveniles, and late juveniles at various locations in the Choptank River (Table 3, Figure 6). A summary of 2014 American Shad stocking production separated by event appears in Table 3. Historical American Shad stocking production summaries for all years are contained in Tables 4 through 7.

American Shad larvae stocking goals were not met in the Choptank River for 2013 (Table 1). The project was ultimately able to stock a large number of early juveniles, which are valuable to assess hatchery contribution (Table 1, Table 5). American Shad late juvenile stocking goals were met for 2014.

In 2014, a decline in the number of fertilized eggs brought into the hatchery negatively influenced larval stocking numbers. Unfavorable weather conditions during the egg collection season were responsible for this decline.

Table 3. *2014 Maryland Department of Natural Resources American Shad stocking events in the Choptank River. Mark is the day age of OTC larval immersion. In 2014 late juveniles were marked with a combination of a day 3, 6 immersion mark and a single 10-day OTC feed mark.*

Date	Life stage	Mark	Number
5/05/14	Larvae	Day 3,6,10	400,000
5/10/14	Larvae	Day 3,6,10	330,000
5/13/14	Larvae	Day 3,6,10	190,000
5/15/14	Larvae	Day 3,6,10	470,000
5/22/14	Early Juvenile	Day 3, 6	40,000
5/28/14	Early Juvenile	Day 3, 6	101,000
6/03/14	Early Juvenile	Day 3, 6	40,000
6/10/14	Early Juvenile	Day 3, 6	15,000
6/11/14	Early Juvenile	Day 3, 6	1,000
6/17/14	Early Juvenile	Day 3, 6	140,000
6/18/14	Early Juvenile	Day 3, 6	1,500
6/19/14	Early Juvenile	Day 3, 6	47,500
6/23/14	Early Juvenile	Day 3, 6	35,000
7/14/14	Late Juvenile	Day 3,6 & 10-day OTC feed	50,000

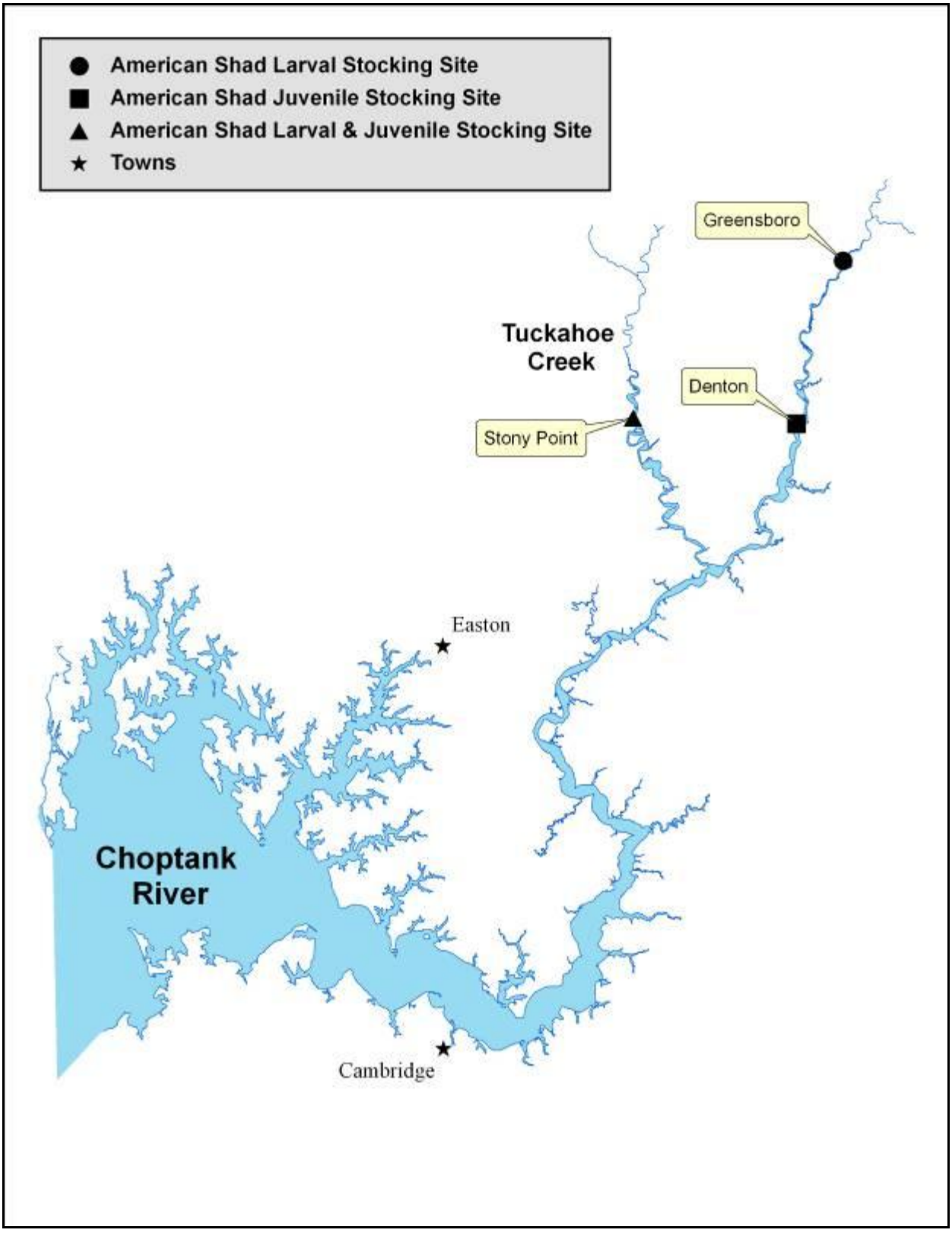

Figure 6. *Maryland Department of Natural Resources Choptank River American Shad stocking sites in 2014.*

Table 4. *Historical stocking summary for larval and juvenile American Shad in the Patuxent River since the inception of the restoration effort (1994-2009).*

Patuxent River American Shad

Year	Larvae	Early Juveniles	Late Juveniles
1994	14,000		89,760
1995	346,000		121,124
1996	655,000		173,994
1997	1,345,000		60,040
1998	61,000		16,726
1999	526,000		60,377
2000	349,000	37,250	26,765
2001	364,000	77,500	21,903
2002	472,000	124,750	24,968
2003	717,000	108,000	31,061
2004	537,000	93,000	36,571
2005	708,000	93,000	40,873
2006	720,000	222,300	93,808
2007	431,000	170,500	34,382
2008	490,000	150,000	0
2009	758,000	130,000	25,954
2010	0	0	0
2011	0	0	0
2012	0	0	0
2013	0	0	0
2014	0	0	0
Total	**8,493,000**	**1,206,300**	**832,352**

Table 5. *Historical stocking summary for larval and juvenile American Shad in the Choptank River since the inception of the restoration effort (1996-2014)*

Choptank River American Shad

Year	Larvae	Early Juveniles	Late Juveniles
1996	626,000		115,110
1997	1,245,000		32,612
1998	136,000		16,885
1999	442,000		64,956
2000	357,000		64,369
2001	0	15,000	32,483
2002	1,020,000	100,000	23,118
2003	1,322,000	167,500	0
2004	675,000	125,000	28,898
2005	1,930,000	170,000	41,483
2006	1,720,000	199,800	0
2007	980,000	139,000	0
2008	985,000‡	35,000	0
2009	980,000	139,000	0
2010	3,725,000	530,000	34,272
2011	1,621,922	269,500	45,000
2012	3,692,956	548,000	69,900
2013	3,120,000	441,000	40,000
2014	1,390,000	421,000	50,000
Total	**24,982,878**	**3,299,800**	**659,086**

‡ *Stockings include 495,000 day 3,6,9 marked larvae. Only day 3 marked larvae are used in abundance estimates.*

Table 6. *Historical stocking summary for larval and juvenile American Shad in Marshyhope Creek since the inception of the restoration effort (2002-2009).*

Marshyhope Creek American Shad

Year	Larvae	Early Juveniles	Late Juveniles
2002	100,000	39,000	9,074
2003	243,000	50,000	0
2004	238,000	33,000	0
2005	205,000	40,000	0
2006	500,000	100,000	0
2007	0	137,000	0
2008	335,000‡	119,500	0
2009	330,000	78,000	0
2010	0	0	0
2011	0	0	0
2012	0	0	0
2013	0	0	0
2014	0	0	0
Total	**1,951,000**	**596,500**	**9,074**

‡ *Stockings include 85,000 day 3,6,9 marked larvae. Only day 3 larvae are used in abundance estimates.*

Table 7. *Historical stocking summary for larval and juvenile American Shad in the Nanticoke River since the inception of the restoration effort (1995-2006). Only fish raised and stocked by Maryland Department of Natural Resources are included. The state of Delaware also raises and stocks shad for the mainstem Nanticoke River and those figures are not included in these data.*

Nanticoke River American Shad

Year	Larvae	Early Juveniles	Late Juveniles
1995	34,000		8,400
1996	0		0
1997	152,000		0
1998	0		0
1999	0		0
2000	0		0
2001	40,000		0
2002	90,000	20,000	13,347
2003	324,000	73,500	0
2004	100,000	60,000	0
2005	275,000	60,000	0
2006	0	40,500	0
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
2012	0	0	0
2013	0	0	0
2014	0	0	0
Total	**1,015,000**	**254,000**	**21,747**

Sub-project 2

A. "Assess the contribution of hatchery-produced fish to the resident/pre-migratory stock in the Patuxent River and Choptank River."

B. "Monitor the abundance and mortality of larval and juvenile shad using marked hatchery-produced fish".

Materials and Methods

Juvenile American Shad were collected by seine from the Patuxent River and Choptank River from late summer to early fall of 2014. The Patuxent River was sampled weekly from 6 August to 7 October. Sampling was precluded on 13 August, 10 September, and 1 October due to previous commitments (Figure 7). The Choptank River (Figure 8) was sampled weekly from 5 August through 17 October.

A seine 61.0 meters long, 3.1 meters deep, with 6.4mm stretch mesh, was deployed by boat into deep water and pulled to shore by hand at established seine sites. All by-catch species were enumerated and recorded. Juvenile American Shad were collected from the seine, placed in plastic bags, labeled, and stored on ice. Upon return to the lab, the samples were frozen to -9 °C.

These samples were subsequently thawed and measured (FL and TL in mm). Sagittal otoliths were successfully removed from 444 juvenile American Shad captured from the Choptank River and 24 shad captured from the Patuxent River. Otoliths were mounted on 76.2 mm x 25.4 mm glass slides with Crystalbond 509 (Aremco Products, Ossining, NY).

Mounted otoliths were lightly ground on 600 grit silicon carbide wet sandpaper and viewed under epi-fluorescent light at 400X magnification at 50-100 watts with a Zeiss Axioscop 20 microscope. The presence and location of OTC mark epi-fluorescence was recorded. Epi-fluorescence is a technique in which transmitted light in the wavelength of 490-515 nm is allowed to strike the specimen. The specimen then absorbs this light energy and reflects light of a longer wavelength back through the microscope objective.

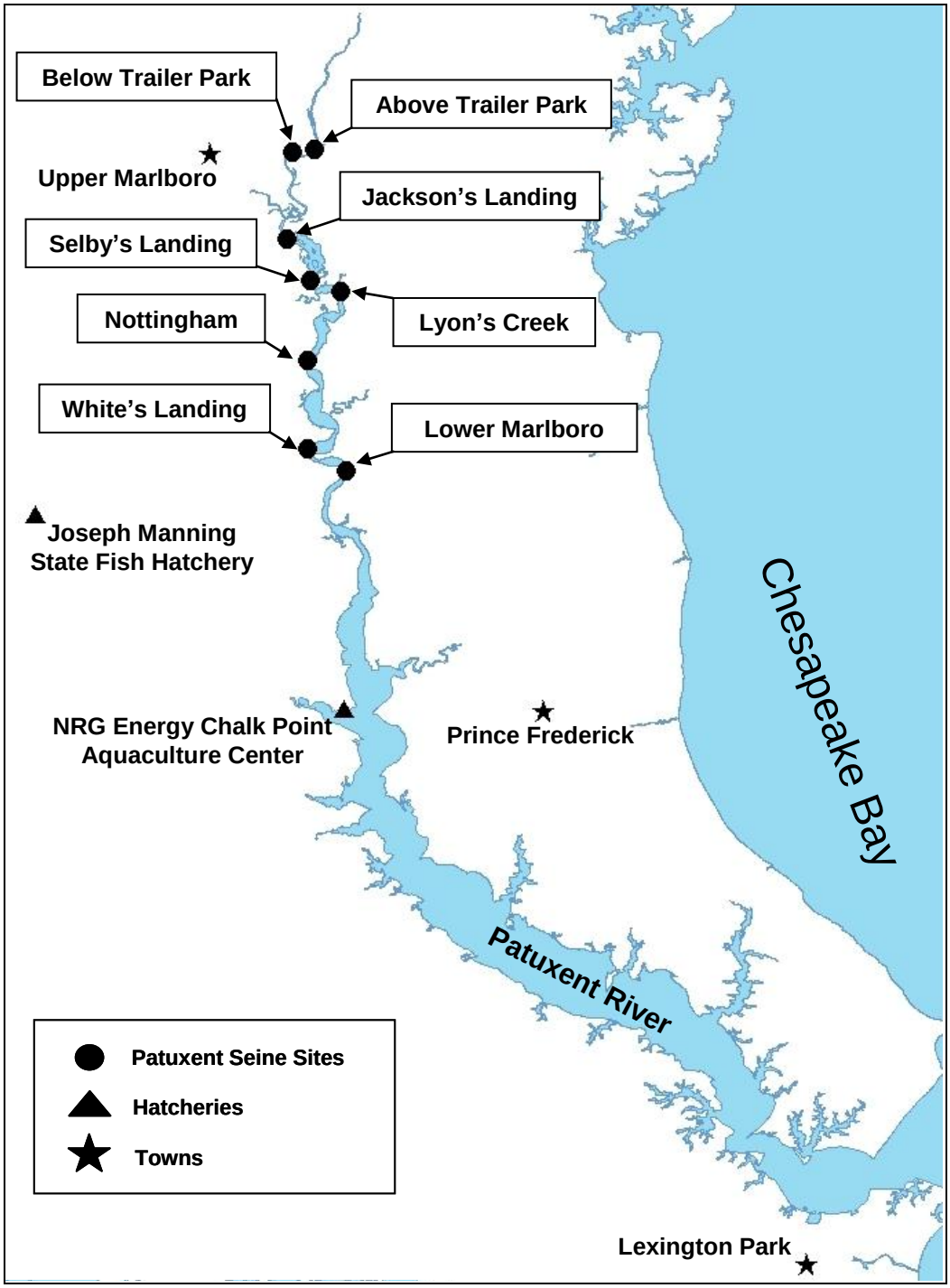

Figure 7. *Maryland Department of Natural Resources Patuxent River juvenile American Shad survey seine sites sampled in 2014.*

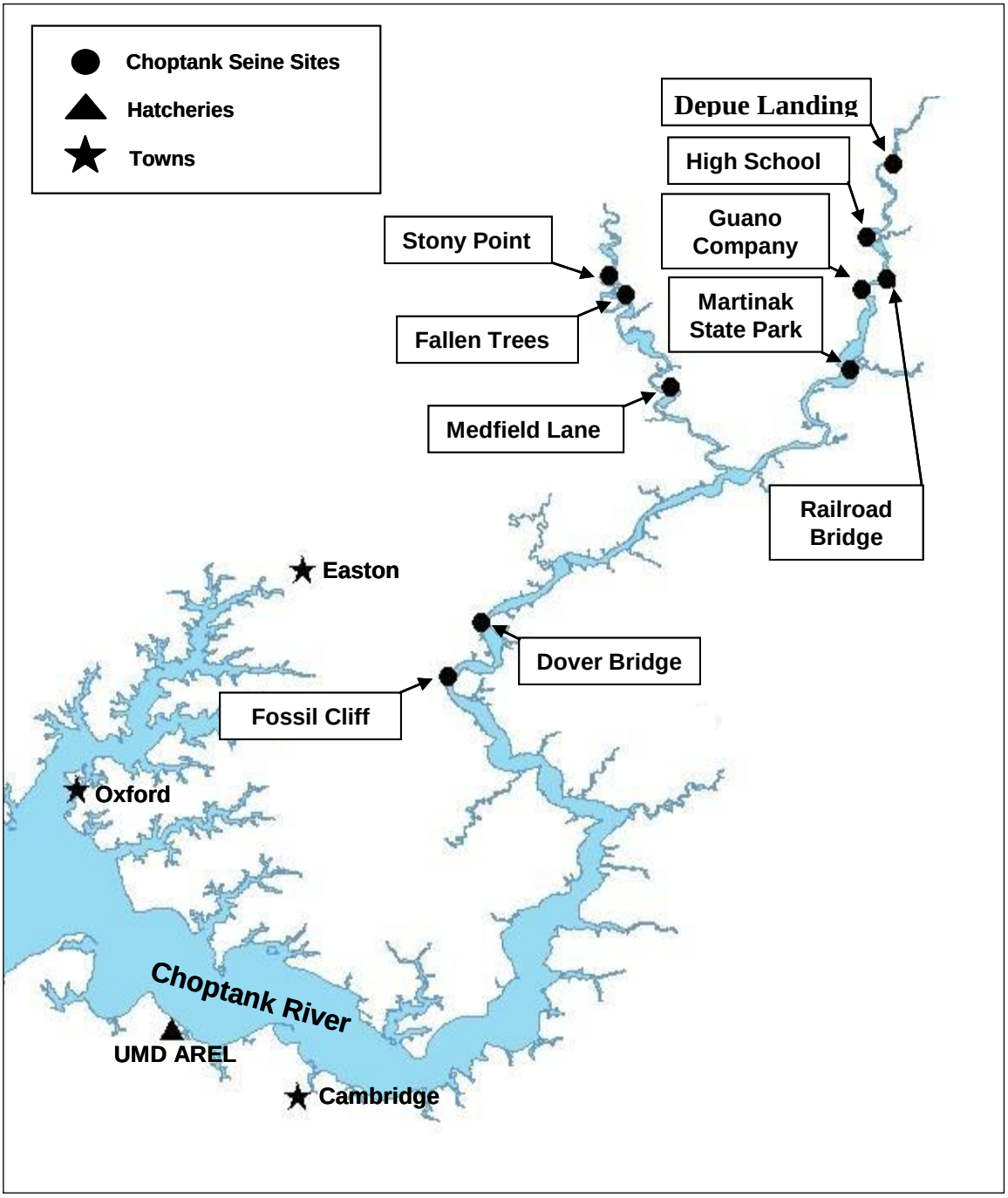

Figure 8. *Maryland Department of Natural Resources Choptank River juvenile American Shad survey seine sites sampled in 2014.*

***CPUE and Geometric Means*:**

The juvenile index is described by calculation of a CPUE. CPUE is defined as the number of captured juvenile American Shad divided by the number of seine hauls completed. Indices of relative abundance are presented as the total arithmetic mean (AM) catch per haul and geometric mean (GM) catch per haul. The GM has been adopted by the ASMFC as the preferred index of relative abundance. The GM is a more precise statistical tool for handling the data because it is not as sensitive to a single large sample value. American Shad are schooling fish and subject to these types of captures with a seine net. Since the inception of this project, CPUE has been used to quantify indices of relative abundance. As a bridge between previous F-57-R progress reports, the 2008 report indicated AM and GM. All indices of relative abundance from 2009 on will be reported by GM only.

Mortality and Abundance Estimates:

In addition to providing future brood fish, juvenile stocking is valuable as a pre-migratory stock assessment tool through use of a multiple marking and recapture technique. Hatchery stocking is also used to evaluate the efficacy of stocking different life stages and the eventual impact to the returning adult population.

There are assumptions made when using these types of estimates as described by (Ricker 1975).

- The marked fish suffer the same natural mortality as the unmarked fish.
- The marked fish are as vulnerable to capture as are the unmarked ones.
- The marked fish do not lose their mark.
- The marked fish become randomly mixed with the unmarked; or the distribution of fishing effort (in subsequent sampling) is proportional to the number of fish present in different parts of the body of water.
- All marks are recognized and reported on recovery.
- There is only a negligible amount of recruitment to the catchable population during the time of recoveries are being made.

Estimates of survival, instantaneous mortality and abundance were calculated for American Shad in the Choptank River.

Estimates of juvenile abundance, mortality and survival were derived from the following:

Larval survival to juvenile stocking was calculated by (Ricker 1975):

$$S_1 = (R_{12})\, M_2 / (M_1)\, R_{22}$$

$$\text{Variance } S_1 = S_1^2 \{(1/R_{12}) + (1/R_{22}) - (1/M_1) - (1/M_2)\}$$

where M_1 is the number of fish marked at the start of the first interval (larval stocking), M_2 is the number of fish marked at the start of the second interval (early juvenile stocking), R_{12} is recaptures of larval marked fish in the second interval (after early juvenile stocking), R_{22} is recaptures of early juvenile interval marked fish in the second interval or (after early juvenile stocking), and S_1 is the survival rate of larvae during interval one (from the time of marking larvae in interval one to time of marking early juveniles in interval two).

Instantaneous mortality is derived from survival estimates and is used in conjunction with stocking data to calculate juvenile abundance:

$$Z = -\ln S_1 / \text{interval}$$

Where Z is instantaneous mortality rate and S_1 is survival rate.

Abundance of juvenile shad prior to out migration was also calculated by Chapman's modification to the Peterson estimate (Ricker 1975):

$$N = \{(C+1)(M+1)\} / (R + 1)$$

where N is the population estimate, M is the number of marked fish stocked, C is the number of fish examined for tags (total captures) and R is the number of marked fish that were recaptured (larval or early juveniles).

From Ricker (1975): Calculation of 95% confidences limits based on sampling error using the number of recaptures in conjunction with Poisson distribution approximation.

Chapman's modification (1951):

$$N^* = \{(C+1)(M+1)\} / (R_1 + 1)$$

Where R_1 is from Pearson's formula to calculate upper and lower limits:

$$R_1 = R + 1.92 \pm 1.960\sqrt{R + 1.0}$$

Results and Discussion

Patuxent River

This study collected 24 wild American Shad juveniles and no hatchery produced American Shad in the Patuxent River by seine in 2014. Patuxent River American Shad have not been stocked since 2009; therefore no juvenile abundance estimates were calculated (2010-2014). However few, wild American Shad were collected for twelve consecutive years (1998-2009). In 2009, this study collected two (0.01%) wild, unmarked American Shad juveniles and very few in subsequent years (2010-2012). The lack of American Shad captures suggests recruitment failure from 2009 through 2012 (Table 8). In 2013 and 2014 recaptures indicated that juvenile recruitment is occurring. It's the third highest total of wild juveniles caught since the inception of stocking efforts, and the second year in a row where double digit (24) wild juveniles were captured.

The MDNR Striped Bass Seine Survey documents annual recruitment for young-of-the-year (YOY) Striped Bass and relative abundance of many other anadromous fish species in the Chesapeake Bay. Since 2005, anadromous species such as Blueback Herring, American Shad, Hickory Shad, White Perch and Yellow Perch have declined. One contributory cause could be the tremendous resurgence of the pre-migratory population of Striped Bass *Morone saxatilis,* which forage on these fish in the Chesapeake Bay and its tributaries when they out-migrate as juveniles. (Eric Durell, MDNR pers. comm.)

The Maryland section of the 2007 ASMFC American Shad stock assessment report stated that; "Trends in relative abundance of adults and juveniles have declined in recent years even though the ocean intercept fishery has been closed. American Shad stocks in Maryland remain at historically low levels. This may be because of mortality undefined in this report. The percent of repeat spawning American Shad trended up in most systems and may be indicative of poor ocean survival" (ASMFC 2007). There are also indications that there may be increased predation of adult shad during their spawning run (Crecco *et al*. 2006). In Maryland waters, adult and juvenile American Shad are potential prey for Striped Bass, Flathead Catfish or Blue Catfish.

Patuxent River trends in wild juvenile abundance have declined since 2005 (Figure 9). With constant, level stocking effort since 2002, wild origin juvenile shad should have continued to increase as was documented in the first five years of the restoration effort. This decline indicates mortality to either out migrating juveniles, sub-adults/adults foraging in the ocean, or both. If there is increased mortality in the ocean, whether from ocean fishing by-catch or from coastal adult predation, future wild American Shad juvenile abundance in our target tributaries

will be difficult to predict.

Table 8. *1995-2014 Maryland Department of Natural Resources American Shad summer juvenile abundance estimates in the Patuxent River. Figures were calculated using Chapman's modification to the Peterson equation (95% confidence interval, numbers may not add up due to rounding). Juvenile stocked origin includes fish stocked as 30-d early juveniles and 90-d late juveniles. No hatchery marked American Shad were stocked in the Patuxent River in 2010-14, so estimates were not calculated for those years.*

Year	Larval Stocked Origin	Juvenile Stocked Origin	Wild Origin	Wild captures	Total Juveniles
1995	78,500	73,300	0		151,800
1996	81,000	153,600	0		234,600
1997	116,000	48,100	0		164,100
1998	0	9,200	1,800		11,000
1999	18,000	53,200	800		72,000
2000	700	43,200	3,600		47,600
2001	12,300	69,300	13,100		94,800
2002	173,700	131,800	35,600	17	341,000
2003	180,700	141,700	65,000	45	387,400
2004	43,600	168,000	16,000	18	227,600
2005	114,500	105,200	46,600	55	266,300
2006	81,300	318,400	17,300	10	417,000
2007	31,500	176,000	13,600	19	221,100
2008	49,900	150,800	9,100	8	209,800
2009	54,800	148,000	1,700	2	204,500
2010	N/A	N/A	N/A	0	N/A
2011	N/A	N/A	N/A	4	N/A
2012	N/A	N/A	N/A	1	N/A
2013	N/A	N/A	N/A	24	N/A
2014	N/A	N/A	N/A	24	N/A

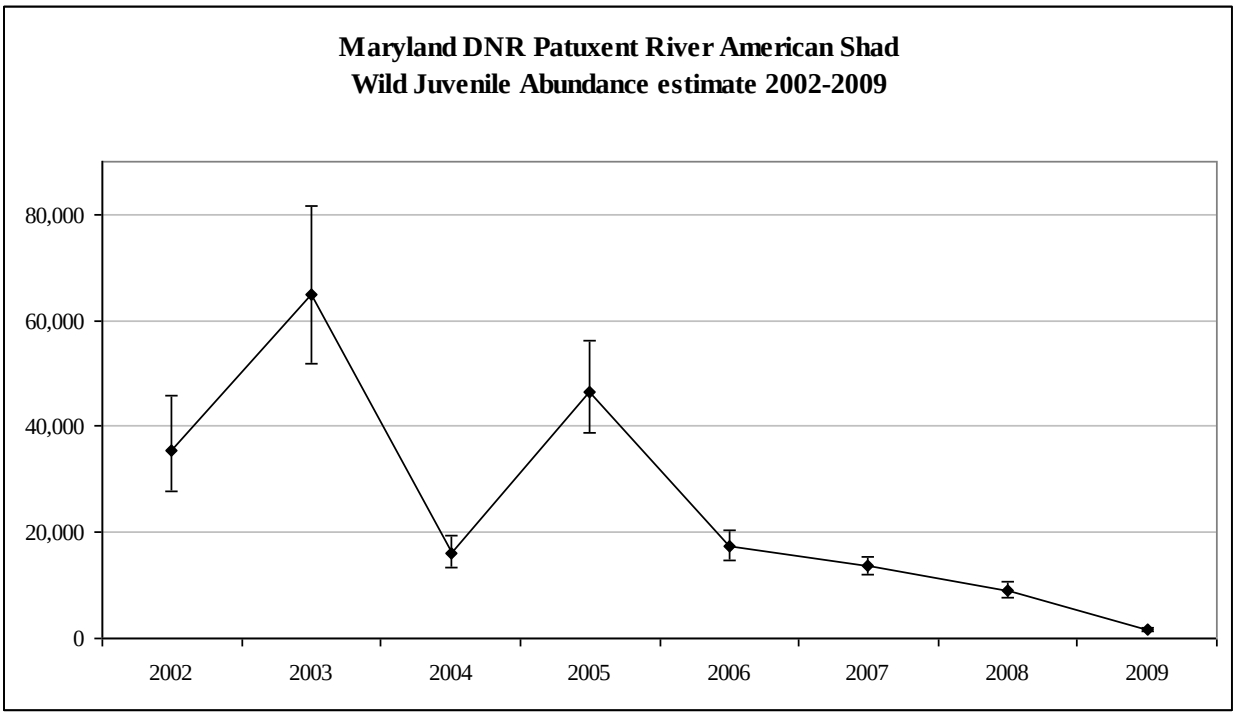

Figure 9. *2002-2009 Maryland Department of Natural Resources American Shad summer juvenile wild abundance estimates in the Patuxent River. Figures were calculated using Chapman's modification to the Peterson equation (95% confidence interval.)No estimates were generated in 2010-14.*

Choptank River

This study collected and successfully analyzed 443 American Shad juveniles from the Choptank River in 2014 (Table 9). Among 2014 samples, 92% were of hatchery origin and 8% were wild origin. Of these captures, 21% were day 3, 6, 10 marked larvae, 66% were day 3, 6 marked early juveniles and 5% were late juveniles. Late juveniles were marked during their larval phase on day 3 and 6. A single 10 consecutive day (10-day) feed mark was administered from 30 June to 9 July for the Choptank River fish. There was no opportunity to stock late juvenile fish into Tuckahoe Creek due to reduced availability of that life stage.

Table 9. *Number and location of American Shad juveniles collected in the Maryland Department of Natural Resources 2014. Choptank River seine survey. n=number of juveniles collected before analysis for hatchery marks.*

Site	8/5	8/12	8/19	8/25	9/3	9/9	9/16	9/23	9/30	10/6	10/16	Grand Total
Depue Landing	1	1	1	1	0	2	3	1	4	1	0	**15**
High School	10	0	7	1	4	0	10	2	3	2	7	**46**
Railroad Bridge	0	2	5	5	1	5	1	2	3	1	0	**25**
Guano Company	7	16	6	3	0	24	19	12	1	1	7	**96**

Martinak State Park	18	2	3	2	3	2	1	0	2	1	0	**34**
Medfield Lane	1	3	0	3	1	8	0	14	1	4	1	**36**
Fallen Trees	0	1	2	8	3	1	10	8	2	16	4	**55**
Stony Point	0	5	0	1	0	6	0	3	0	1	0	**16**
Dover Bridge	1	4	0	10	0	1	1	0	3	1	0	**21**
Fossil Cliff	1	4	0	0	1	12	12	0	64	4	1	**99**
Grand Total	**39**	**38**	**24**	**34**	**13**	**61**	**57**	**42**	**83**	**32**	**20**	**443**

Juvenile American Shad were collected at all seven of the established seine sites on the Choptank River, and three additional seine sites on the Tuckahoe Creek in 2014 (Table 9). Unlike the Patuxent River, in which the distribution of sampling sites appear to cover the distribution of juveniles, the sample sites in the Choptank River and Tuckahoe Creek did not include the upper range of the juveniles in these tributaries. The area of greatest juvenile abundance was most likely sampled, but the lack of acceptable seining sites precludes collections upstream from Depue Landing on the Choptank River and Stony Point on the Tuckahoe Creek. Downstream juvenile habitat is typically limited by salinity (Figure 10). The conditions during the 2014 summer seine survey represented a drier than normal year, driving salinities across all seine sites above historic averages. Salinity in 2014 ranged from 0.12 to 6.90 ppt, while historical salinity in the current stations (2004-13) ranged from 0.15 to 4.31 ppt.

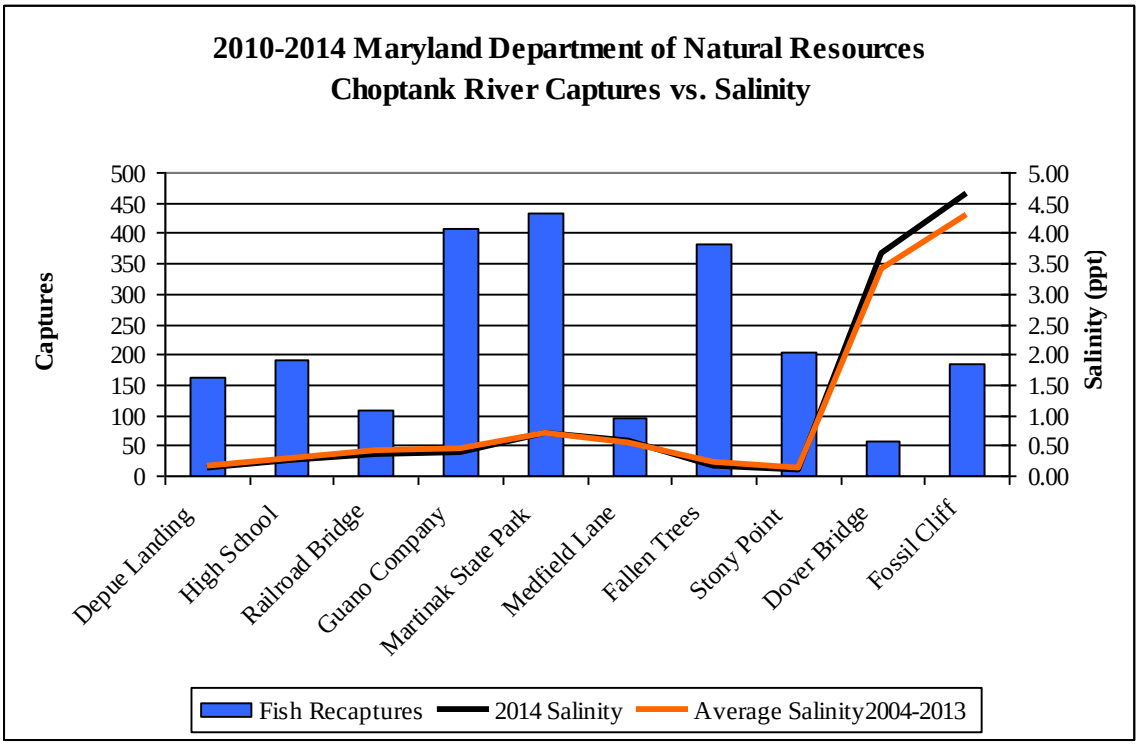

Figure 10. *2014 Maryland Department Natural Resources summer seine survey American Shad juvenile catch composition and salinity by site in the Choptank River and Tuckahoe Creek. Fallen Trees, Stony Point and Medfield Lane are sample sites on the Tuckahoe Creek.*

Choptank River: Geometric Means:

MDNR amended the restoration approach to temporarily suspend stocking the Patuxent River and Marshyhope Creek and apply all project resources towards stocking and monitoring in the Choptank River.

During the 2014 juvenile seine survey, 443 American Shad were captured on the Choptank River and the Tuckahoe Creek. The 2014 GM was calculated twice, first using the original Choptank seine sites and then with the addition of three seine sites added on the Tuckahoe Creek in 2010. The GM for the original seine sites is calculated to be 2.21, which is greater than the average of 1.09 from the previous fourteen years (Figure 11). The 2014 GM for the Choptank River and Tuckahoe Creek combined was calculated to be 2.38. This is the fifth year to calculate combined GM for the Choptank River and the Tuckahoe Creek. These data will be the baseline for future GM calculations assuming that the new stocking and sampling strategies remain constant. This maximum stocking impact resulted in a GM two to three times higher than the 10-year average on the Choptank River in 2010. The GM has increased significantly during the sampling period of 1999 to 2014 P=0.009 (Figure 11).

Prior to 1996 stocking efforts, no American Shad were captured in this tributary in 35 years (sampling conducted by other MDNR projects prior to 1996).

Higher transport mortality has been observed when stocking early juveniles in the Choptank River when water temperatures exceed 24°C. It is possible that post-stocking mortality of early juveniles is higher at this distant location. Travel time for stocking early juveniles from culture ponds to the Denton boat ramp is approximately two hours. The differences observed between Patuxent River and Choptank River early juvenile mortality suggest the need to avoid stocking distant rivers with juvenile American Shad during the heat of the day. An effort has been made to transport and stock juveniles during early morning hours. Early juvenile marked fish are recaptured in the summer seine survey; therefore these handling procedures appear to be working. Handling juvenile shad in this manner will be monitored in future years.

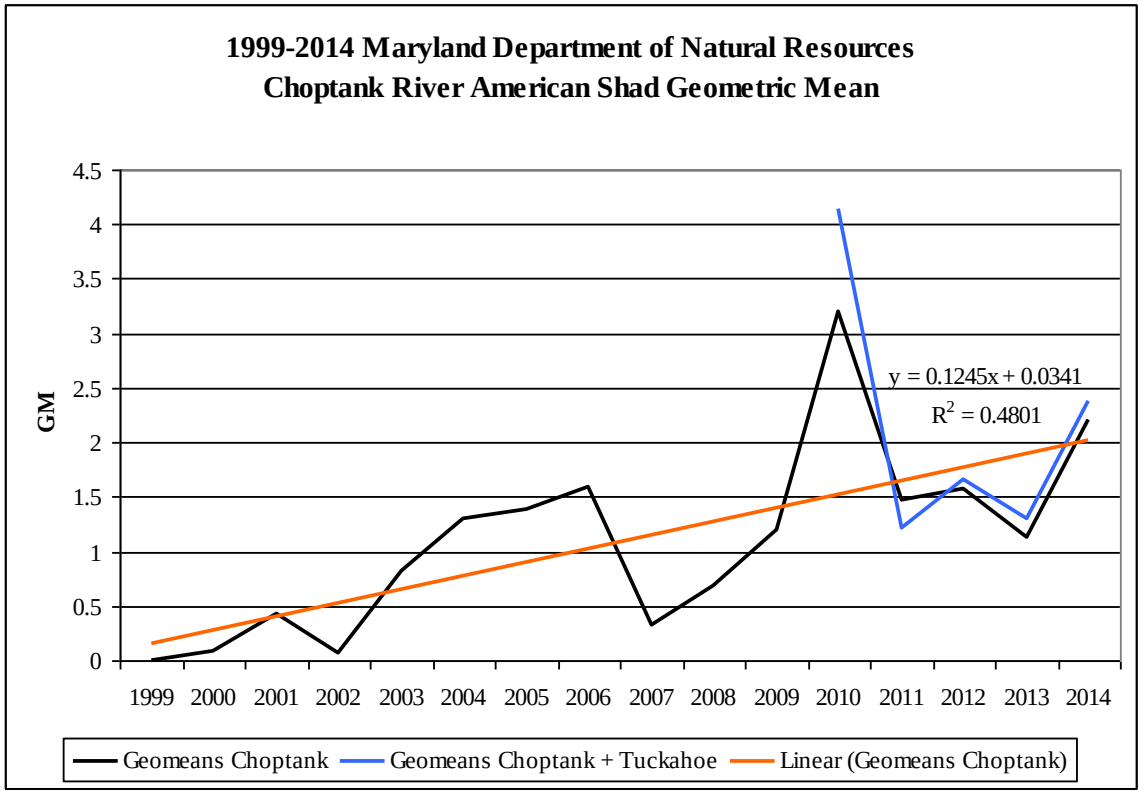

Figure 11. *Maryland Department of Natural Resources Choptank River American Shad historic geometric mean (GM). Data were generated from the permanent summer seine survey sites conducted on the Choptank River from 1999-2014. 2010-14 show the GM of combined river systems (Choptank River and Tuckahoe Creek).*

Choptank River: Mortality and Abundance Estimates

Estimates of larval survival, instantaneous mortality and juvenile abundance were calculated for Choptank River American Shad in 2014. Survival of day 3,6,10 marked larval stocked American Shad to early juvenile stocking in the Choptank River was calculated to be 0.0958 for the 17-day period. Daily mortality of larval stocked shad to the time of early juvenile

stocking was calculated to be Z=0.1380, (±2 SE=0.0228). Juvenile abundance of day 3,6,10 larval stocked American Shad (May 22, 2013) was calculated to be 133,000 using survival estimates and stocking data. Traditionally using early juvenile recaptures to estimate total juvenile abundance is a more accurate measure than larval or late juvenile recaptured fish. Using early juvenile total abundance estimates, individual recapture rates for the various life stages are a more accurate measure of total juvenile abundance. Total abundance using the early juvenile recaptures and individual recapture rates was calculated to be 633,600.

Survey recapture rates can be used to estimate the composition of the juvenile stock on May 22 (Table 10). Using these data, larval stocked origin abundance was calculated to be 133,022. Total juvenile abundance in the Choptank River (May 22, 2014) was calculated by Chapman's modification to the Peterson estimate at 633,642 (upper limit=710,048 lower limit=565,437). Abundance of wild origin juveniles was estimated at 48,632 in 2014. The 2014 wild abundance estimate was lower than the 2012 estimate of 61,317 but higher than the estimate of 44,248 in 2013, 15,900 in 2011, 41,500 in 2009 and 17,100 wild juveniles in 2008 (Figure 12, Table 11).

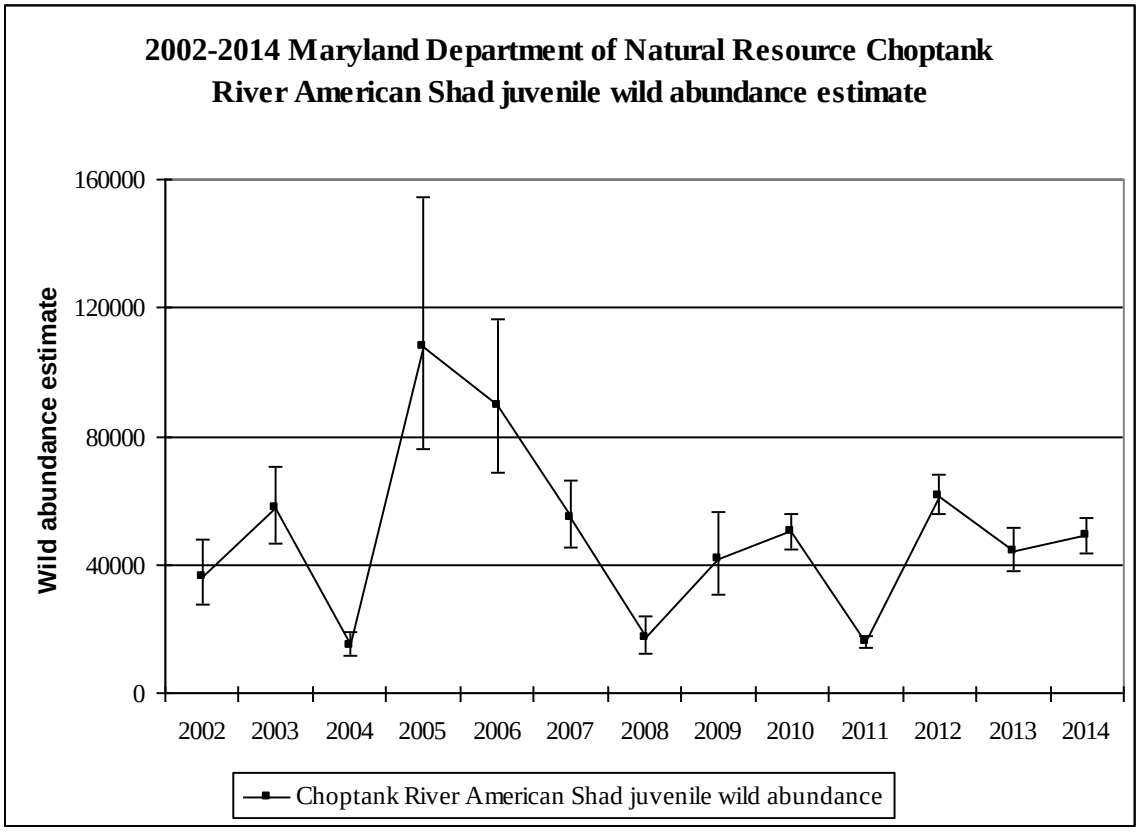

Figure 12. *2002-2014 Maryland Department of Natural Resources American Shad summer juvenile wild abundance estimates in the Choptank River. Figures were calculated using Chapman's modification to the Peterson equation (95% confidence interval.)*

It should be noted that the 2006 analysis of relative value indicated poor post-stocking early juvenile survival in the Choptank River due to transport stress. Underestimation of stocked early juveniles would result in overestimation of larval survival. The early juvenile recapture rate in 2007 was 40% compared to 19% in 2006. MDNR biologists altered stocking procedures for early juveniles in 2007. One horsepower trash pumps were carried on the stocking trucks to temper juvenile shad before stocking. Fish were tempered until temperature and salinity in the tank were within one degree Celsius and 1.0 ppt salinity of the river value. This procedure added a considerable amount of time that fish were aboard the transport tank, but we feel this procedure increased survival of early juvenile stocked shad. Further investigation of early juvenile mortality will continue in future years.

Table 10. *Estimates of American Shad juvenile abundance in the Choptank River on May 22, 2014. Estimates were calculated using Chapman's modification to the Peterson equation (95% confidence interval).*

Life stage	Peterson Estimate	Upper Limit	Lower Limit
Larval stocked	133,022	149,062	118,703
Early juvenile stocked	420,521	471,229	375,256
Late juvenile stocked	31,468	35,262	28,080
Wild juveniles	48,632	54,496	43,397
Totals	**633,642**	**710,048**	**565,437**

Total juvenile abundance was calculated annually for the Choptank River since 1996 (Table 11). Minkkinen et al (1997) estimated Choptank River total juvenile American Shad abundance in 1996 at 109,300. No wild fish were collected during that assessment. The population was comprised of 28,600 larval stocked fish and 80,700 fish that had been stocked as juveniles.

In comparison, estimated total abundance at the time of early juvenile stocking was 404,000 in 2002 and 349,700 in 2003. The 2005 and 2006 estimates indicated the highest levels of total juvenile abundance (over 1 million) observed to date in the Choptank River (Table 11). The average juvenile abundance from 2002 to 2014 is 592,292. The 2014 abundance estimate of 635,800 is above the twelve year average and is the fourth highest estimate in the past eight years.

Survival of larval anadromous species can vary widely from year to year as observed in previous spawning seasons (Table 12). These larvae are sensitive to both biotic and abiotic factors during the first weeks of development (Crecco, 1985). Larval-origin juvenile abundance is not correlated with larval stocking effort however. This is due to variable larval survival from

year to year (Table 12). Total juvenile abundance is variable according to the level of stocking effort and larval survival for each year and is positively correlated with larval stocked-origin juvenile abundance (r^2 =0.641448, P<0.001883).

Based on past observations, recruitment to the juvenile population is set by approximately 30 days and mortality is very low past this point. Direct comparisons of Choptank River abundance to other target tributaries, such as the Patuxent River, are not appropriate without consideration of the quality and quantity of juvenile habitat available. Based on historic juvenile recaptures from this project, the Choptank River has much more juvenile habitat than the Patuxent River and Marshyhope Creek, so at this time it is unknown whether an abundance estimate of 1,000,000 is high for this river. Based on the amount of available juvenile nursery habitat, the Choptank River should be able to support at least four times the abundance of the Patuxent River. Considering past abundance estimates of more than 400,000 juveniles in the Patuxent River, it is possible that the Choptank River could support between 1.5 million and 2.0 million juveniles.

Table 11. *1996-2014 American Shad summer juvenile abundance estimates in the Choptank River. Figures were calculated using Chapman's modification to the Peterson equation (95% confidence interval, numbers may not add up due to rounding).*

Year	Larval Stocked Origin	Early juvenile Stocked Origin	Late Juvenile Stocked Origin	Wild Origin	Total Juveniles
1996	28,600	80,700		0	109,300
1997‡	NA	NA		NA	NA
1998‡	NA	NA		NA	NA
1999‡	NA	NA		NA	NA
2000‡	NA	NA		NA	NA
2001‡	NA	NA		NA	NA
2002	231,200	100,500	36,200	36,200	404,000
2003	124,000	168,400		57,300	349,800
2004	159,400	125,900	4,200	14,700	304,200
2005	922,300	170,800	11,400	108,200	1,212,700
2006	748,300	200,500		89,500	1,038,300
2007	148,700	139,500		54,800	343,000
2008	48,200	35,400		17,200	100,800
2009	377,500	151,000		41,500	570,000
2010	268,600	531,000	11,000	50,000	860,400
2011	68,000	270,300	7,400	15,900	361,500
2012	154,000	549,000	20,000	61,300	784,300
2013	135,200	442,500	113,100	44,200	735,000
2014	133,000	420,500	31,500	48,650	633,600

‡Insufficient sample size to calculate estimate

Table 12. *Estimates of stocked American Shad larval survival and instantaneous mortality to the date of early juvenile stocking in the Choptank River, 2002-2014.*

Year	Instantaneous Mortality (Z)	±2 S.E.	Survival	Interval (days)
2002	0.0677	0.0015	0.2255	22
2003	0.1243	0.0304	0.0943	19
2004	0.0690	0.0810	0.2346	21
2005	0.0290	0.2007	0.4757	24
2006	0.0440	0.1305	0.4335	19
2007	0.0652	0.0407	0.1511	29
2008	0.0459	0.0383	0.0800	55
2009	0.0571	0.1066	0.2850	22
2010	0.0975	0.0135	0.0720	27
2011	0.1444	0.0117	0.0417	22
2012	0.0691	0.0091	0.0416	46
2013	0.1571	0.0133	0.0432	20
2014	0.138	0.0228	0.0958	17

Natural recruitment is occurring in the Choptank River according to otolith analysis. No wild juveniles were captured in the first five years of the restoration effort. Total captures were low (1997-2000), and no wild juveniles were captured until 2001 (Table 13). Poor hatchery production in past years prevented stocking sufficient numbers of larvae in the Choptank River. We estimate that a minimum of 1,000,000 larvae should be stocked in the Choptank River to ensure recaptures, juvenile recruitment and subsequent sufficient adult recruitment. The restoration effort decided to temporarily suspend stocking the Patuxent River and Marshyhope Creek and apply all project resources towards stocking and monitoring in the Choptank River. This strategy should enable collection of sufficient information to accurately estimate the survival and abundance of juvenile American Shad in the Choptank River each year.

Since the inception of the stocking effort, that target was met in 1996, 1997 and 2002-06, 2009, 2010, and 2012-2014 (Tables 4 through 7). In 2014, 1.390 million larvae and 421,000 early juveniles were stocked. In past years, limited hatchery production was distributed to the Patuxent River as first priority. Therefore, low production years shorted the Choptank River. Starting in 2008 the American Shad wild abundance has stayed consistent (Figure 12). Juvenile abundance estimates in 2010 suggested a mild resurgence of the wild component in the Choptank River from a low of 17,200 in 2008 to 50,000 in 2010. While 2011 saw a decrease to 15,900 from the previous year's estimate of 50,000, the 2012 estimate indicated signs of rebound with 61,300. The 2014 wild population estimate of 48,800 is less than 2012 and 2010 estimates but remains consistent with the 2013 estimate. This year's estimate of 48,800 is greater than project lows of 15,900 in 2011 and 14,700 in 2004.

In 2014, 443 juveniles were collected. The Choptank River wild juvenile abundance estimate was calculated using larval and early juvenile stocking events. This estimate calculated 48,800 wild juveniles. In 2007 and 2008, wild origin juveniles accounted for sixteen and nineteen percent of the recaptures, two of the highest recorded wild recaptured events. In 2009 the wild recaptured percentage substantially declined to seven percent from nineteen percent, which initiated a percentage point decrease each year through 2011 (Table 13). Since 2011, the wild recaptures have remained consistent. We would expect the wild component of the juvenile population to continue to increase steadily each year as hatchery fish from the 2010 year class are recruited to the spawning population. The 2010 year class was the first full year class strictly designated to the Choptank River watershed. (Table 11).

In 2014, three adult American Shad were captured on the Choptank River during sampling. Even though only three adult American Shad were captured on the Choptank River, wild juveniles were captured, demonstrating reproduction. In the past, different sections of the river have been sampled with electrofishing equipment, with little or no success, suggesting spawning habitats and locations remain unknown. An effort will be made in 2015 using gill nets to find adult spawning locations of American Shad since spawning is known to occur.

An increase in out-migrating juvenile shad mortality or coastal adult mortality may impact wild juvenile abundance.

Table 13. *Juvenile American Shad recaptures in Choptank River from Maryland Department of Natural Resources summer seine survey since inception of the restoration effort, 1996-2014. Data are percentage of origin composition of all juveniles collected by the survey. n=number of captured juvenile American Shad that were successfully analyzed for origin.*

Sample year	n	Larval stocked origin	Early juvenile stocked origin	Late Juvenile stocked origin	Wild fish
1996	99	37%	NA	63%	0%
1997‡	NA	NA	NA	NA	NA
1998	1	100%	NA	0%	0%
1999	13	36%	NA	62%	0%
2000	8	0%	NA	100%	0%
2001	41	0%	32%	51%	17%
2002	200	58%	25%	8%	9%
2003	188	36%	48%	NA	16%
2004	145	52%	41%	1%	5%
2005	213	76%	14%	1%	9%
2006	290	72%	19%	NA	9%
2007	263	43%	41%	NA	16%
2008	94	43%	38%	NA	19%
2009	151	66%	26%	NA	7%
2010	551	31%	62%	1%	6%
2011	341	19%	75%	2%	5%

Sample year	n	Larval stocked origin	Early juvenile stocked origin	Late Juvenile stocked origin	Wild fish
2012	550	20%	70%	3%	8%
2013	299	18%	60%	15%	6%
2014	443	21%	66%	5%	8%

‡There are no data available for 1997.

Sub-project 3.

Analyze the contribution of hatchery origin American Shad to the adult spawning population and monitor the recovery of naturally produced stocks.

Objectives

Patuxent River and Choptank River spawning ground surveys commenced in 1999 to collect adult American Shad. Restorative stocking of American Shad in these two target tributaries began in 1994 and 1996, respectively. Three quantifiable population variables have been identified for evaluation of restoration progression of adult American Shad spawning stocks in the targeted rivers.

1) *Estimate catch-per-unit effort (CPUE) in each targeted river using geometric mean.*
2) *Estimate the contribution of hatchery produced fish to the adult spawning populations.*
3) *Estimate the frequency of virgin and repeat-spawning.*

Methods and materials

Sampling was conducted at historical American Shad spawning areas described by anecdotal data and concentrated in river reaches where shad were encountered during previous sampling efforts (Table 12, Figure 8). The survey was conducted with a Smith-Root electrofishing boat model SR18-E (Vancouver, WA). The Patuxent River was sampled weekly from 11 March to 10 June and the Choptank River was sampled 19 March to 5 June during day time hours coinciding with high tides. Each survey was accomplished with three people, one person piloting the boat and two people netting shad from the bow. Each river was sampled in an upstream to downstream direction with constant voltage applied to the entire reach. Total pedal time (s) was recorded for calculating relative abundance (CPUE). Water temperature (°C), dissolved oxygen (ppm), and conductivity (µS/cm) were obtained using a YSI Pro 2030 water quality meter (Yellow Springs, OH) and a Secchi disk was used to quantify turbidity (cm).

Adult American Shad are sampled in areas that display similar physical characteristics in each river. The survey reach on both rivers generally includes the lowermost areas near the salt wedge to the uppermost areas just below the fall line (Table 12, Figure 8). In the Patuxent River, this includes the area from the wastewater treatment plant located north of the intersection of Bayard Road and Sands Road (4500 block of Sands Road) to approximately 2.44 miles upstream just above the Patuxent River 4H Center. In the Choptank River this area extends from the Route 313 Bridge in Greensboro, Maryland to approximately 1.28 miles upstream.

River	*Starting latitude/longitude*	*Ending latitude/longitude*
Patuxent River	38° 53’ 08.24” N 76° 40’ 29.53” W	38° 51’ 05.09” N 76° 41’ 33.04” W
Choptank River	38° 59’ 11.91” N 75° 47’ 11.29” W	38° 58’ 36.79” N 75° 48’ 06.79” W

Table 14. *Maryland DNR adult American Shad electrofishing survey starting and ending coordinates for target tributaries.*

In each of the targeted rivers it is likely that shad utilize tidal freshwater areas downstream of our collection sites, but increasing river width and depth reduces capture efficiency with electrofishing gear. Anecdotal evidence indicates that substantial spawning habitat and fish movement also exists upstream of currently sampled stream reaches, but sampling upstream habitat is limited by electrofishing boat access.

A sub-sample of no more than 20 American Shad was collected per day for age, otolith, and coded wire tag (CWT) presence analysis. All other observed shad were counted to calculate CPUE. Fish collected were measured for total length (TL; mm), fork length (FL; mm) and sex was determined. Scale samples were taken for age estimation and spawning mark interpretations, and otoliths were extracted to identify hatchery (OTC) marks. All hatchery origin American Shad are marked with OTC, which allows for collection of data on hatchery contribution to the juvenile abundance estimate and the adult spawning stock composition. Shad scales were cleaned, mounted between glass slides, and age was estimated and spawning attempts were counted using a microfiche reader. Two biologists interpreted the scales independently. In cases where readers disagreed on an age/spawning attempt analysis, a consensus age was used as the final age. Scales/spawning attempt were aged using methods described by Cating (1953). Otoliths were processed using methods described for juvenile fish in Sub-project 2.

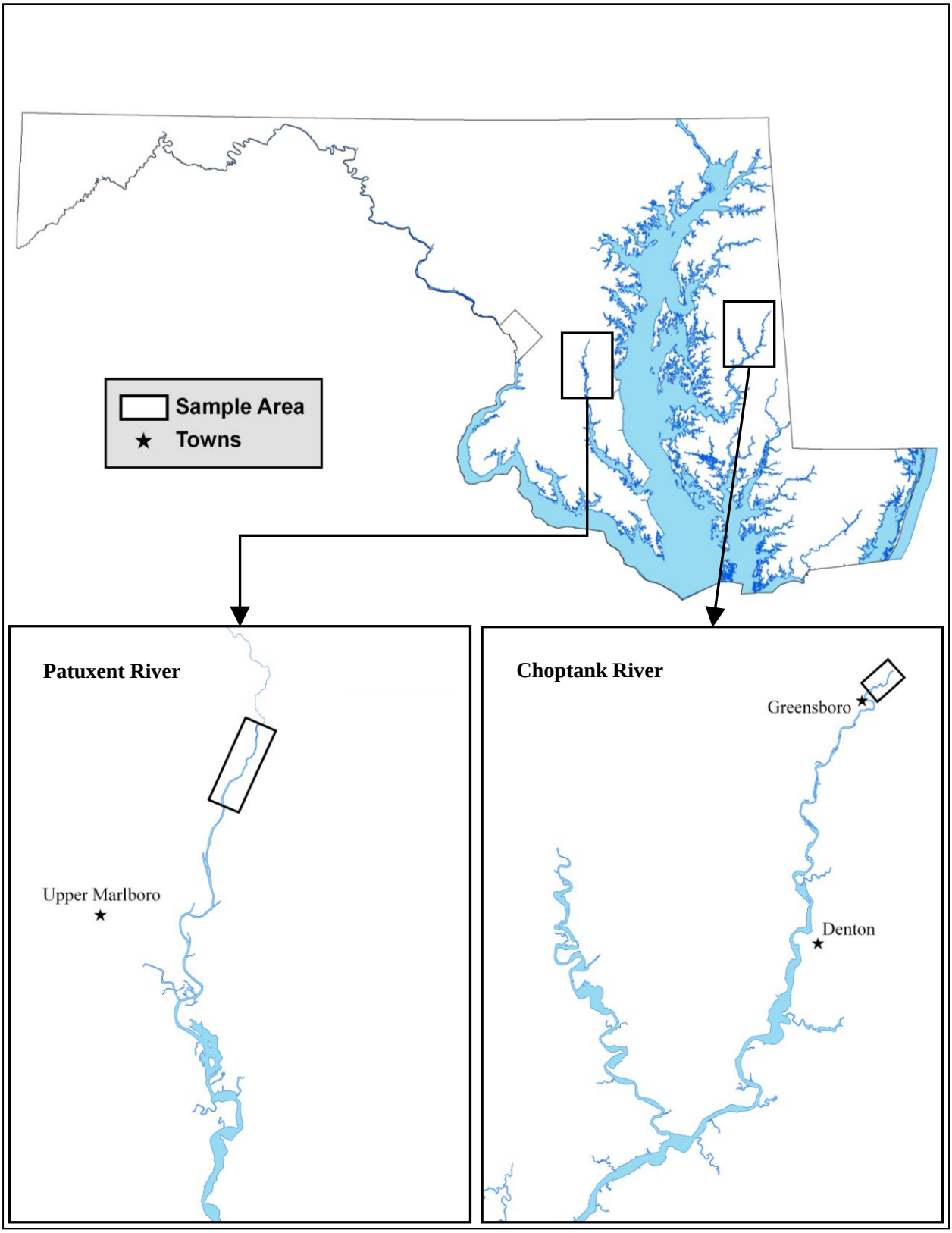

Figure 13. *Maryland DNR adult American Shad electrofishing survey areas sampled in 2014.*

Catch Per Unit Effort Analysis

Relative abundance was omitted in reports prior to 2008 due to changes in sampling protocol and the overall nature of sampling these highly turbid rivers. Beginning in 2008, attempts were made to standardize CPUE data and apply those results to evaluate restoration progression. Data were standardized using the number of shad encountered per day divided by the shock time in minutes applied to the river the day of sampling. Since the number of sampling days is different each year, the mean CPUE is calculated to obtain an annual CPUE. Adult sample data are unavailable prior to 1999 and any data prior to 2001 are deficient of the necessary catch and effort data to obtain a standard CPUE. Standardization of CPUE advanced in 2011 with the implementation of bracketing CPUE data. Before 2011, data were collected starting the first week of April and lasting until the CPUE hit zero at the end of the spawning run. Protocol implementation calls for a CPUE zero at the beginning and end of the survey season to better understand how long fish remain in the spawning area each year.

The geometric mean (GM) has been adopted by this project as the preferred index of relative abundance to evaluate stock status and restoration progress. The GM is calculated from the $\log_e(x+1)$ transformation, where x is the number of American Shad encountered per shock time (min). The number one is added to all catches in order to transform zero catches, because the log of zero does not exist (Ricker 1975). Since the $\log_e$-transformation stabilizes the variance of catches (Richards 1992) the GM estimate is more precise than the AM and is not as sensitive to a single large sample value. It is almost always lower than the AM (Ricker 1975). The one was subtracted from the final number after final calculations. Differences among annual GMs were tested using a two-way analysis of variance (ANOVA) on the $\log_e(x)$ transformed data. Means were considered significant at the $P<0.05$ level.

Origin Composition (Hatchery vs. Wild)

The percentage of hatchery versus wild origin American Shad adults sampled on the spawning grounds provides insight into the impact of stocking larval and juvenile shad to the adult population. The presence of adult hatchery origin fish on the spawning grounds early in restoration may stimulate annual natural reproduction, something that has not occurred in decades prior to the restoration efforts. As restoration efforts continue, a transition from a high proportion of hatchery origin fish to a high proportion of wild fish year after year indicates natural reproduction events leading to successful recruitment to adulthood. Identifying shifts from predominantly hatchery origin adults to a wild origin population indicates a substantial effect upon the adult spawning stock population. This variable is sensitive to small sample sizes.

Virgin and Repeat-Spawning Compositions

A third estimator uses analysis of virgin and repeat-spawning compositions. Through examination of American Shad scales, the number of times a fish embarks on an annual spawning run during its lifetime can be determined. The composition of virgin and repeat-spawn frequency observed on the spawning grounds provides additional insight to population stability and recruitment. Low levels of virgin-spawners may indicate problems associated with juvenile recruitment to the adult stock or poor spawning success. Conversely, a high level of virgin-spawners usually indicates successful recruitment of individual year classes to the adult spawning stock. A substantial contribution of virgin-spawners and several repeat-spawning classes utilizing the spawning grounds year after year is indicative of a stable spawning stock. Choptank River annual spawning stock sample sizes remain very low and preclude any virgin and repeat-spawning composition analysis.

Results

Restoration progress for American Shad in the two target tributaries cannot be completely evaluated using only spawning ground electrofishing sampling. Substantial project experience indicates that adult American Shad can more easily avoid electrofishing capture than the closely related Hickory Shad. The result is that American Shad adults are probably not fully represented in spawning ground sampling and sample sizes remain too small for the traditional analysis applied to the Hickory Shad captures of the same survey. The larval and juvenile survival, mortality and abundance estimates presented in sub-project two of this report serve as an important indicator of restoration progress. Analysis of the adult data can provide additional insight. Efforts will be made in 2015 to use gill nets to capture adult American Shad downstream of traditional electrofishing areas. By increasing the number of adult American Shad recaptures, hatchery contribution determination will be a significant factor for tributary stability.

Patuxent River Adult American Shad Spawning Stock

A total of 24 American Shad were observed on the Patuxent River in 2014, of which 20 American Shad were retained for length, otolith, and scale analysis. Surveys were conducted from 11 March to 10 June when water temperatures ranged from 5.5° to 21.6°C (Figure 14). All fish were captured and observed during the period from 15 April to 4 June when water temperatures were16.8-20.8°C.

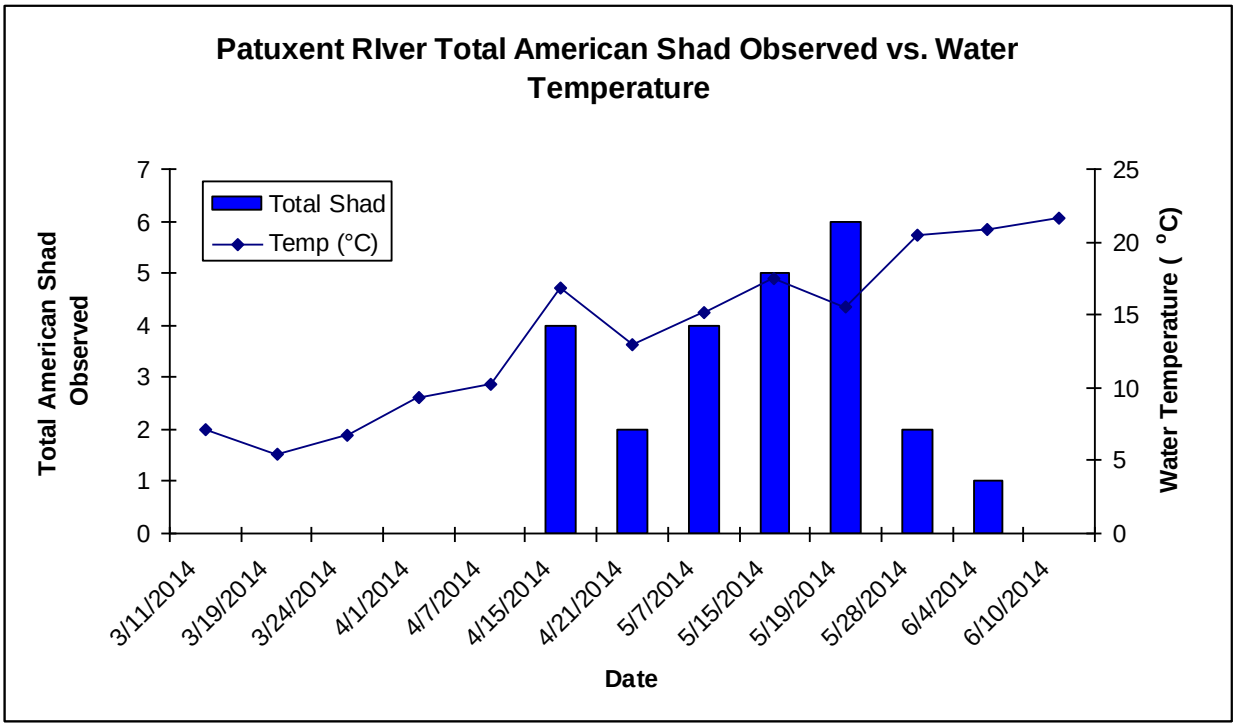

Figure 14. *2014 Maryland DNR electrofishing collections and observations of adult American Shad in Patuxent River.*

Over the course of the time series, the Patuxent River American Shad survey has typically established a zero CPUE value at the beginning of the spawning run, but does not detect zero values to end the spawning run. In ten out of the last fourteen years, a zero CPUE value was detected at the start of the American Shad spring run (Figure 15). However, only six out of the last fourteen years have established a zero value at the end of the run.

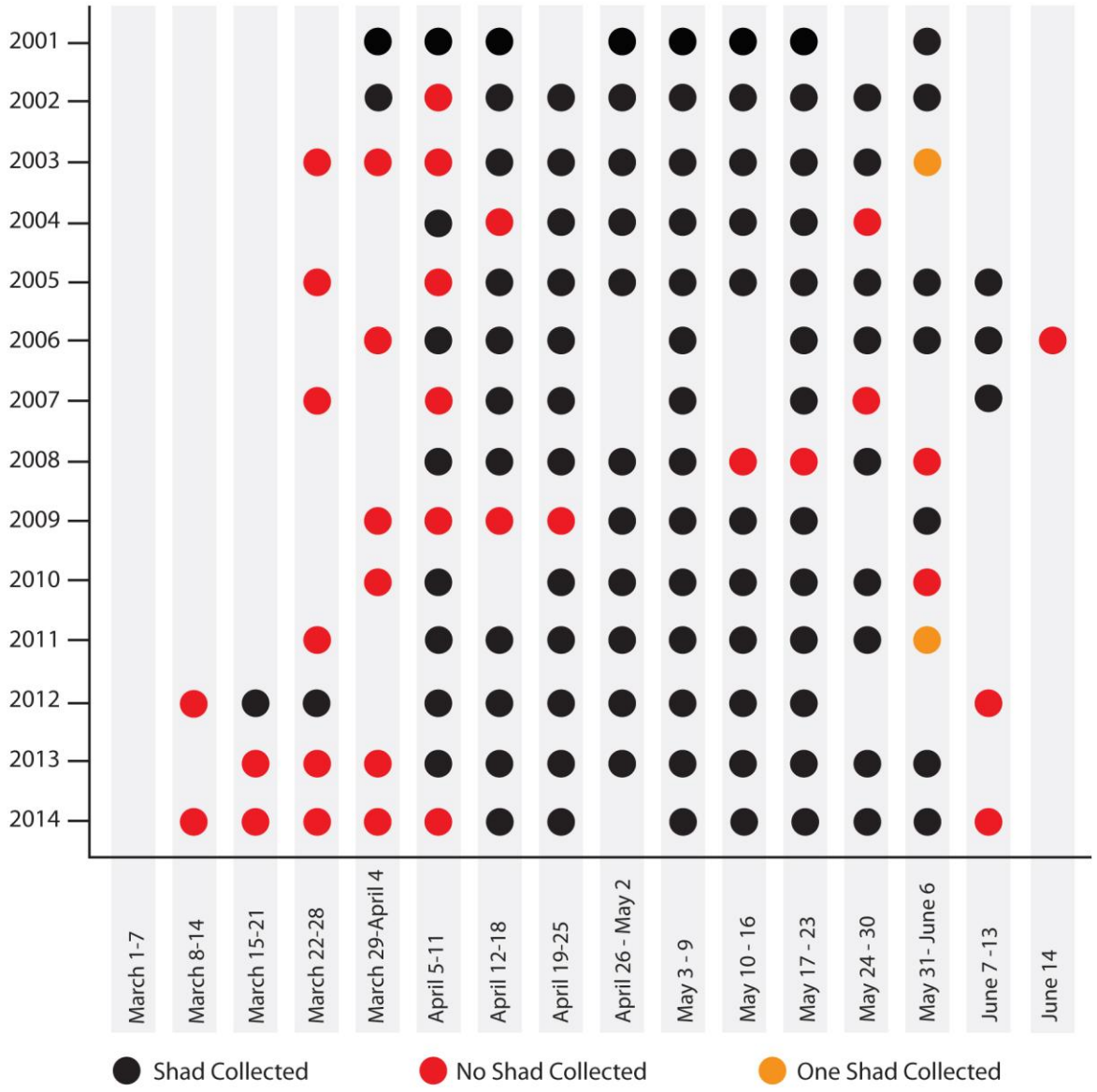

Figure 15. *2001-2014 Maryland DNR Patuxent River American Shad sampling dates sorted by seven day increments, with corresponding zero, one, or more than one total shad number.*

Patuxent River American Shad CPUE

During the thirteen weeks from 11 March to 10 June 2014 when American Shad were surveyed on the Patuxent River, the mean relative abundance (GM) was calculated as 0.028 fish/min (Figure 16). Although the GM is well below the 14 year average (0.18 fish/min), this value falls within the typical variation that has been observed over the course of the time series.

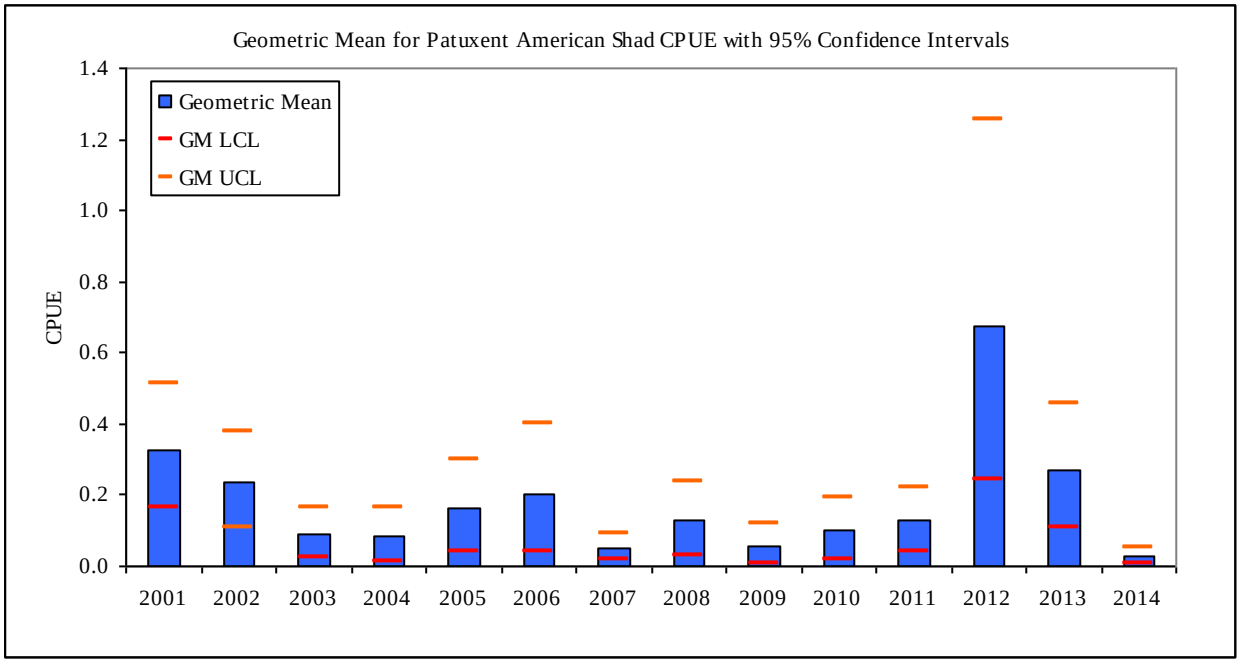

Figure 16. *2014 Maryland DNR electrofishing survey, Patuxent River American Shad geometric mean (GM) with 95% confidence intervals of CPUE for sample years 2001-14.*

Patuxent River American Shad Origin Composition (Hatchery vs. Wild)

In 2014, 20 American Shad were collected from the Patuxent River for origin composition analysis through otolith OTC mark interpretations. All samples were successfully assessed for origin (Figure 16). The sample composition consisted of 12 hatchery origin (60%) and 8 wild origin (40%).

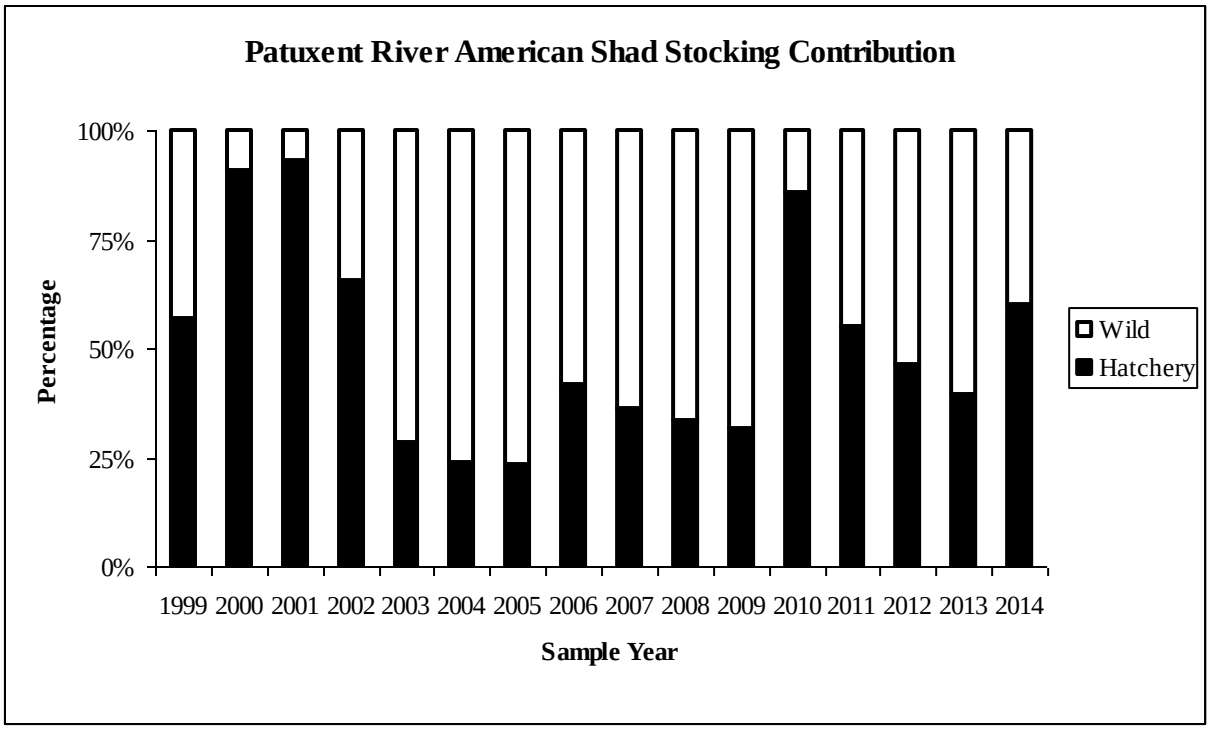

Figure 17. *Maryland DNR electrofishing survey Adult American Shad origin composition on spawning grounds of the Patuxent River from 1999-2014.*

Patuxent River American Shad Virgin and Repeat-Spawning Compositions

A total of 20 American Shad scale samples were collected in 2014. All 20 scale samples collected were successfully analyzed to determine the annual spawning attempt composition. The 2014 sample population consisted 30% second-time spawners, 45% third-time spawners, and 25% fourth-time spawners (Table 15). The sample size of American Shad captured in 2014 was so low that there are no appreciable conclusions that can be made from the repeat spawning data, as these distributions likely do not exhibit what is actually occurring in the population.

Table 15. *2014 Maryland DNR electrofishing survey. Patuxent River American Shad spawning attempt composition for sample years 2002-14.*

		Spawning Attempts					
Year	**Sample Size (n)**	**Virgins**	**2**	**3**	**4**	**5**	**6**
2002	103	12 (12%)	50 (49%)	31 (30%)	10 (10%)		
2003	35	1 (3%)	7 (20%)	16 (46%)	9 (26%)	2 (6%)	
2004	28	4 (14%)	7 (25%)	5 (18%)	8 (29%)	2 (7%)	2 (7%)
2005	82	33 (40%)	23 (28%)	17 (21%)	9 (11%)		
2006	87	27 (31%)	26 (30%)	17 (20%)	8 (9%)	7 (8%)	2 (2%)
2007	23	1 (4%)	8 (35%)	8 (35%)	4 (17%)	2 (9%)	
2008	39	5 (13%)	7 (18%)	20 (51%)	3 (8%)	4 (10%)	
2009	19	1 (5%)	3 (16%)	9 (47%)	6 (32%)		
2010	32	7 (22%)	9 (28%)	7 (22%)	9 (28%)		
2011	69	31 (45%)	29 (42%)	9 (13%)			
2012	152	33 (22%)	39 (26%)	59 (39%)	20 (13%)	1 (1%)	
2013	117	20 (17%)	33 (28%)	41 (35%)	20 (17%)	3 (3%)	
2014	20		6 (30%)	9 (45%)	5 (25%)		

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Patuxent River American Shad Spawning Stock Discussion

Similar to the Choptank River and Patuxent River Hickory Shad restoration efforts, the Patuxent River American Shad adult CPUE have varied without trend throughout the time series (2002-2014). Unlike Hickory Shad, which experienced a decline in CPUE three years following the completion of the stocking efforts, American Shad experienced a peak in CPUE three years after the stocking efforts ended in the Patuxent River (Figure 16). However, in 2014 the value returned to a level that was experienced during stocking years in this system.

Until recently, analysis of origin composition data of the Patuxent River American Shad spawning stock represented a classic pattern of stocking effects on a nearly extirpated population (Figure 17). Before restorative stocking began in 1994, the spawning grounds were primarily

comprised of low numbers of wild remnant population American Shad and/or strays from other river systems. In 1999, the first documented hatchery origin adult American Shad was observed on the Patuxent River spawning grounds. After several years of hatchery origin cohorts recruited to the migratory population, hatchery origin adults began to dominate the spawning grounds. The 2000 and 2001 sample populations demonstrate this increased hatchery component on the spawning grounds. In 2003, this population transitioned from a hatchery dominated population to a wild-origin dominated population. The seven-year period from 2003 to 2009 represents the interval in which wild fish dominated the spawning stock population sample. During this period, 69% of the fish on the spawning grounds were of wild origin. This transition to a wild dominated population was hypothesized to be triggered by the progeny of hatchery origin adults returning to spawn as wild adults. In 2010, the spawning stock transitioned back to a predominately hatchery origin composition. Natural spawning success may have been limited due to the relatively low numbers of spawning individuals. This is supported by the low number of wild juvenile seine survey recaptures from 2010-2012. Seine survey data indicate that the annual wild juvenile abundance estimate has decreased over the past nine years (Figure 9). Therefore, low numbers of wild juveniles recruiting to the migrating stock results in relatively low levels of wild adults returning to spawning grounds. In 2012 and 2013, wild fish again dominated the adult American Shad sample in the Patuxent River. However, the 2014 sample was made up of predominately hatchery origin American Shad (60%; Figure 17). Age and spawning attempt analysis correlate 2014 recaptures with stockings from 2007-2009.

Examination of the virgin and repeat-spawning data can be used to evaluate stability or instability in a spawning stock and can aid in the prediction of a stock decline or expansion. A stable American Shad spawning stock consists of a substantial contribution from several spawning classes. However, there are several factors that can impart variability in these distributions, including maturity schedules of males (3-4 years) and females (5-6 years), timing of the spawning run, inter-annual spawning events, annual recruitment of wild fish, number of fish stocked annually and recruitment of stocked fish. It may be possible to remove some of the variability from these distributions by evaluating male and female distributions separately, but there are already small sample size concerns when combining the males and females in these distributions. This is especially true when looking at fish making their fifth and sixth spawning attempt. Rarely are there five fish in these age categories, which are needed to evaluate these distributions statistically (i.e. chi-square analysis rely on sample sizes of 5 individuals or more per bin). Years where small sample sizes of fish are collected leads to uninformative gaps in the time series. Small sample sizes of American Shad were collected from the Patuxent River in

most years over the time series. This resulted in distributions that appeared uniform (2010 and 2014) or spawning attempt classes that contained very few individuals (2003-2004, 2007-2011, 2014), making these distributions uninformative at current recapture levels (Table 15).

Patuxent River American Shad Management Implications

Overall, the American Shad stocking effort in the Patuxent River was successful. The stocking effort resulted in the formation of a population that is reproducing. The adult electrofishing survey was able to capture stability in the data. Throughout the course of the restoration effort (2001-2009) and following cessation of stocking efforts (2010-2014), the relative abundance (CPUE) varied without trend (Figure 16). Because a stable population exists, there is no longer a reason to survey the Patuxent River every year. Some data collection is still appropriate to maintain trend data, and we recommend sampling every three years.

Choptank River Adult American Shad Spawning Stock

Three American Shad were observed on the Choptank River in 2014. All three fish were captured on 28 May when the water temperature was 21.4°C.

Choptank River American Shad Discussion

American Shad adults are not observed in high numbers in the Choptank River survey reach. Catches are low in comparison to Hickory Shad in the same survey reach on the Choptank River (Figure 18). American Shad are encountered in larger numbers in the same sampling areas where adult Hickory Shad are encountered in the Patuxent River. Traditional analyses (CPUE, origin, and spawning attempt composition) provide less robust assessment of the spawn stock population dynamics due to small sample size. To this point, the wild juvenile abundance estimates of sub-project 2 serve as a better indicator of restoration progression in the Choptank River. The increase of adult fish returning to the spawning grounds in 2008 and 2009 was promising, however, in 2010 no adult American Shad were observed. In 2011, nine adult American Shad were observed. This was an increase from 2010, but just barely above the mean of the fourteen-year sample period. Unfortunately, in 2012 no adult American Shad were captured. In 2013, two American Shad were observed, increasing to three observed adult fish in 2014. This continues the trend of low adult American Shad collections in the current Choptank River sample area.

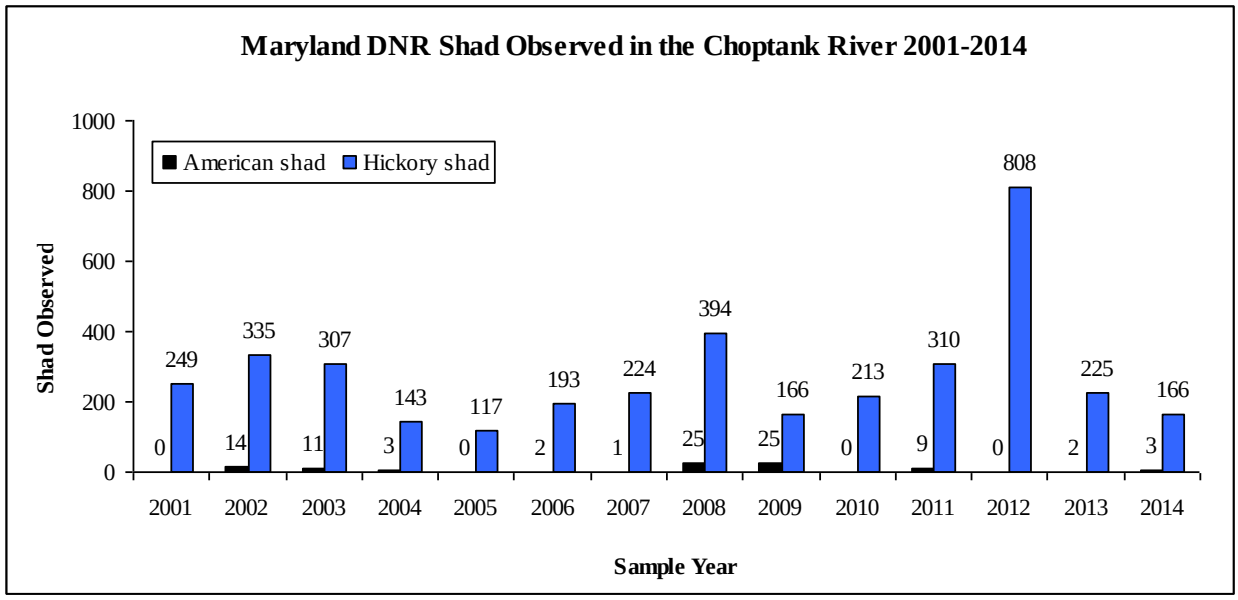

Figure 18. *Maryland DNR electrofishing observations of adult American and hickory shad in Choptank River 2001-2014.*

Prompted by low adult American Shad sample sizes, attempts were made to sample new areas downstream of the historical sampling reach from 2008 to 2010. This reach encompassed the area just below Greensboro boat ramp to approximately 1.87 miles downstream, and was sampled the same day as the historical sampling area. This area is characterized as being wider and deeper than the historical sample area, and is difficult to sample with current electrofishing techniques. In 2008, 15 adult American Shad were observed in the new downstream sample reach. However, in 2009 and 2010 no fish were observed in this downstream section during 14 sampling events. Wild juvenile captures during the summer seine survey in 2009 and 2010 indicate that there is successful recruitment. Sampling of the experimental downstream area was discontinued in 2011. Presence of wild juveniles provides evidence for American Shad utilizing the Choptank River as spawning habitat, but the adult electrofishing sampling protocol does not efficiently capture adults. In 2015, the project will conduct a Choptank River American Shad gill net survey downstream of current electrofishing habitat. This survey will use protocol similar to brood collection in the Potomac River to adequately sample Choptank River adults.

Overall Restoration progress:

Choptank River:

Determining the progression of the American Shad restoration program through time has been difficult due to low numbers of returning adult American Shad and the annual variability of wild juvenile abundance estimates. Even though the wild juvenile abundance has been variable, wild juveniles are captured in the summer seine survey. In 2012 and 2014 there were 34 and 43 wild recaptures, which signifies that wild recruitment is occurring. Because of this, two new surveys will be conducted in 2015 to determine if adult American Shad are spawning in areas downstream of the current survey reach on the Choptank River. Gillnetting will be conducted in the vicinity of Denton, Maryland in attempt to capture adult American Shad returning to the Choptank River. Additionally, larval fish sampling will be conducted in the Choptank River system by the MDNR Fisheries Habitat and Ecosystems Unit, to potentially identify American Shad spawning areas based on the presence of American Shad larvae. Recaptures from these new approaches will determine the direction of the restoration efforts in 2016.

Patuxent River:

An intensive juvenile survey has been conducted in the Patuxent River since 1994. (Sub-project 2). These surveys annually captured hundreds of hatchery juveniles from inception, but no wild American Shad were captured in these surveys until 1998. Since this initial capture of wild juveniles on the Patuxent River in 1998, the wild component of juvenile American Shad steadily increased to a peak of 18% in 2005(Figure 9). These positive indicators in the Patuxent River declined in recent years (2006-12). Reduced American Shad stocking effort and poor larval survival resulted in low juvenile abundance over a four-year period from 1998 to 2001. This low juvenile abundance prevented recruitment to the migratory stock in sufficient numbers to positively impact restoration efforts. This lower larval stocking effort was partly due to a shift to early juvenile culture. Stocking remained relatively constant since early juveniles were incorporated into the stocking strategy in 2000. The negative impacts from 1998-2001 then diminished. Patuxent River juvenile abundance estimates were high in each year from 2002-2009 (mean=242,000), which should provide sufficient adults to recruit to the spawning stock. Even with the steady annual hatchery contribution from 2000-2009, juvenile abundance estimates continued to decline, driven by declining wild recruitment. There were no juvenile American Shad captured in the Patuxent River in 2010, only five juveniles captured in 2011 and none in

2012. Due to the lack of hatchery inputs, an abundance estimate could not be performed from 2010 to date. It is encouraging that 24 wild juveniles were captured in 2013 and also in 2014.

Adult repeat spawning attempt data also suggest a stable population, however statistical analysis cannot be performed due to low numbers of recaptures in several of the time series and spawning attempt assignments (number of attempts).Repeat spawning attempt analysis in 2006 indicated that 20% of all adults had returned at least four times. In contrast, by 2011, 40% of adults sampled were returning for the first time and in 2012, 22% were virgin spawners. The large number of virgin spawners may be a positive trend and may be an indicator that a coast-wide mortality observed prior to 2006 was only temporary. Additional adult CPUE data indicate no trend from later stockings in the early 2000s confirming a somewhat stable population of American Shad without trend in the Patuxent River. In 2012 there was an increase in adult recaptures, which reversed the CPUE trend from a declining population to an expanding population. The trend has reversed but is not significant at this time. Repeat spawn analysis indicate five strong year classes from 2009 to 2013. Small sample sizes in 2014 preclude addition of those samples to the analysis. As previously reported, these data suggest that the coast-wide mortality may only have been temporary.

Project-wide observations:

Stocking efforts appear to be effective in the Choptank and Patuxent rivers. Established Patuxent River adult spawning populations are evident, according to adult CPUE trend data and hatchery contribution composition. CPUE trend data have not significantly changed, while hatchery contribution has declined since the inception of the project. In the Choptank River, the juvenile seine survey CPUE data suggest that natural recruitment occurs there. There has been successful wild recruitment since 2002 and juvenile seine surveys conducted from 2012-2014 averaged 51,000 which are above the nineteen year average of 33,000. No wild juvenile estimates were available from 1996- 2001. The lack of any adult spawning stock population estimates or relative abundance information creates uncertainty. We propose to continue to stock the Choptank River at current established levels, and to develop surveys to better collect the data needed to conduct adult assessment. A adult gill net survey will be conducted downstream of established electrofishing survey areas. Ichthyoplankton (IP) sampling will also occur in the Choptank River system to potentially identify American Shad spawning areas based on the presence of American Shad larvae. Captures from these new approaches will determine the direction of the restoration efforts in 2016.

Data prior to 2006 indicated evidence of coast-wide mortality in American Shad stocks. The Atlantic States Marine Fisheries Commission coordinates management of migratory fish species along the Atlantic Coast. ASMFC documented a steady decline in shad populations in the past. These recent declines were unanticipated by fisheries managers, since long-term restoration programs were beginning to indicate progress. ASMFC believes that there is some unexplained mortality of American Shad stocks and they have formulated several management statements related to this issue.

There are several potential causes for declines in coastal stocks. While there is no "smoking gun", it is likely that mortality is increasing due to one or more factors:

> **In: Stock Assessment Report No. 07-01 (Supplement) of the Atlantic States Marine Fisheries Commission pp155**
> *"Results of data summarized elsewhere in this document suggest declines in many Atlantic coastal stocks of American Shad, especially in the mid-Atlantic and southern New England states. Many causes for this decline have been suggested. They include bycatch in ocean fisheries, former mixed stock harvest from coastal and estuarine locations, increased predation on juvenile and adult shad by piscine and mammalian predators, and losses from down river passage at dams and hydroelectric facilities."*

Commercial by-catch, if it is occurring at a high level, could significantly impact shad populations coast-wide since stocks mix freely during ocean migrations. Fisheries observer coverage is minimal for many species due to resource limitations so it is difficult to accurately assess bycatch from all ocean fisheries. This will be a primary focus of American Shad fisheries managers in the future.

Over the past 20 years, Atlantic Coast striped bass stocks have increased from an abundance of 7,000,000 to over 65,000,000 (ASMFC Annual Report 2008). This dramatic and relatively rapid shift has increased speculation concerning the impact of these large predators to prey populations:

> **In: Atlantic States Marine Fisheries Commission Atlantic Coast Diadromous Fish Habitat: A Review of Utilization, Threats, Recommendations for Conservation, and Research Needs, Habitat Management Series #9 January 2009 pp17**
> *A recent study strongly supports the hypothesis that striped bass predation on adult American Shad in the Connecticut River has resulted in a dramatic and unexpected decline in American Shad abundance since 1992 (Savoy and Crecco 2004). Researchers further suggest that striped bass prey primarily on spawning adults because their predator avoidance capability may be compromised at that time, due to a strong drive to spawn during upstream migration. Rates of predation on ages 0 and 1 alosines was also much lower (Savoy and Crecco 2004).*

The Connecticut River research is a tributary-specific study that is not necessarily applicable to all Atlantic Coast stocks, but it demonstrates the existing concerns of fisheries managers. There

are likely many other factors that contribute to the functional ecological relationship between striped bass and shad. Further obfuscating the issue is a concurrent decline in Atlantic Coast river herring stocks. It is possible that the declining shad population is the result of a combination of impacts (by-catch, predation). The ASMFC Shad and River Herring Technical Committee is investigating and has developed some recommended actions to address the issue.

Due to the broad geographical range and many threats to the various life stages of American Shad, the ASMFC took further action regarding commercial and recreational fisheries. **The 2010 ASMFC annual report stated:**

> "*The Shad and River Herring Management Board approved Amendment 3 to the Shad and River Herring FMP to update the shad management program. The Amendment establishes a coast wide commercial and recreational moratorium, with exceptions for sustainable systems. Sustainability is determined through state-specific management plans, and applies to systems where it is demonstrated that the commercial and/or recreational fishery will not diminish future stock reproduction and recruitment. The Amendment allows any state or jurisdiction to keep its waters open to a catch and release recreational fishery. The Amendment was developed in response to the findings of the 2007 benchmark stock assessment, which indicates that American Shad stocks are currently at all-time lows and do not appear to be recovering.*

Amendment 3 to the Shad and River Herring FMP is encouraging news for the restoration efforts of American Shad in Maryland. The American Shad restoration effort has produced positive results in the past. Since the Potomac River population is stable and the Susquehanna River has trended upward since 2006 (Karen Capossela MDNR pers.comm.), it is possible that this coast-wide mortality was only temporary.

The project will continue to stock American Shad in the Choptank River until adult relative abundance (CPUE) and hatchery contribution to the spawning population can be assessed.

Success of this program relies on natural recruitment from hatchery-produced adults. Fish stocked at larval and early juvenile size successfully imprint to their native rivers and return to spawn. Prior to the restoration effort, there had been no measurable American Shad recruitment in the Patuxent River or Choptank River since the 1970s (Maryland Juvenile Recruitment Survey). Increased angler participation is evident in the Patuxent River, Choptank River and Tuckahoe Creek as anglers now routinely target these fish.

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